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(54) ETHERNET EXTENSION FOR THE DATA CENTER

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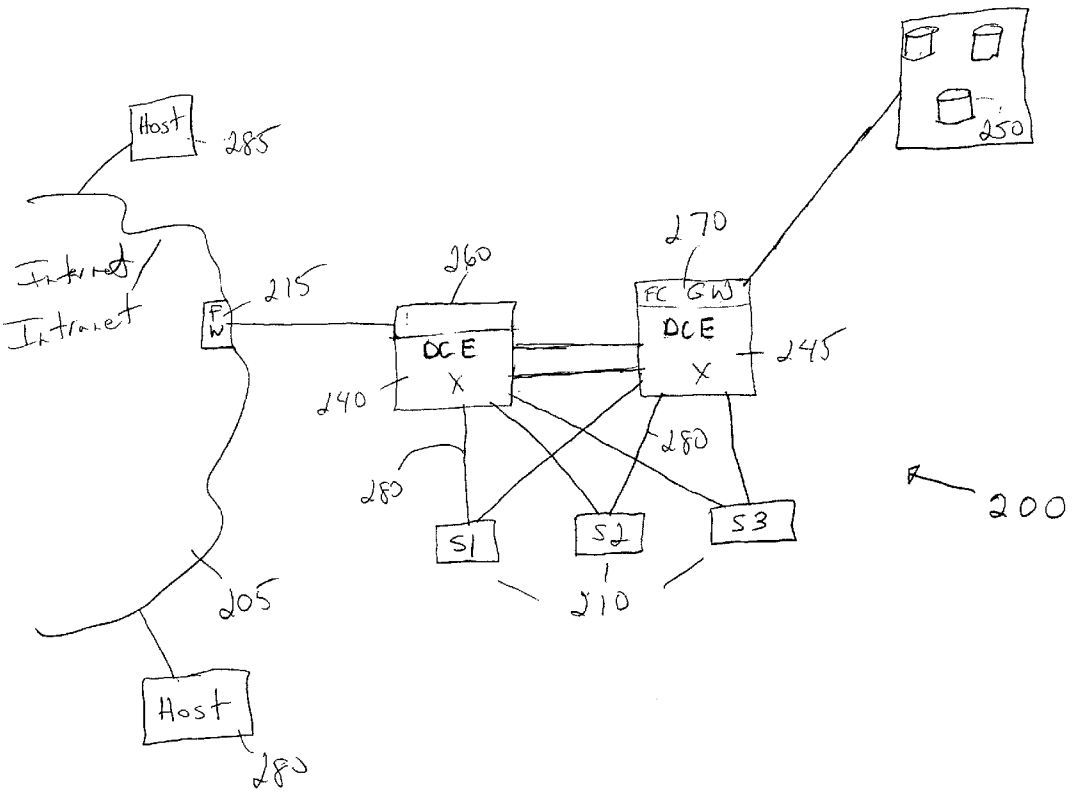
(57) **ABSTRACT**

The present invention provides methods and devices for implementing a Low Latency Ethernet ("LLE") solution, also referred to herein as a Data Center Ethernet ("DCE") solution, which simplifies the connectivity of data centers and provides a high bandwidth, low latency network for carrying Ethernet and storage traffic. Some aspects of the invention involve transforming FC frames into a format suitable for transport on an Ethernet. Some preferred implementations of the invention implement multiple virtual lanes ("VLs") in a single physical connection of a data center or similar network. Some VLs are "drop" VLs, with Ethernet-like behavior, and others are "no-drop" lanes with FC-like behavior. Some preferred implementations of the invention provide guaranteed bandwidth based on credits and VL. Active buffer management allows for both high reliability and low latency while using small frame buffers. Preferably, the rules for active buffer management are different for drop and no drop VLs.



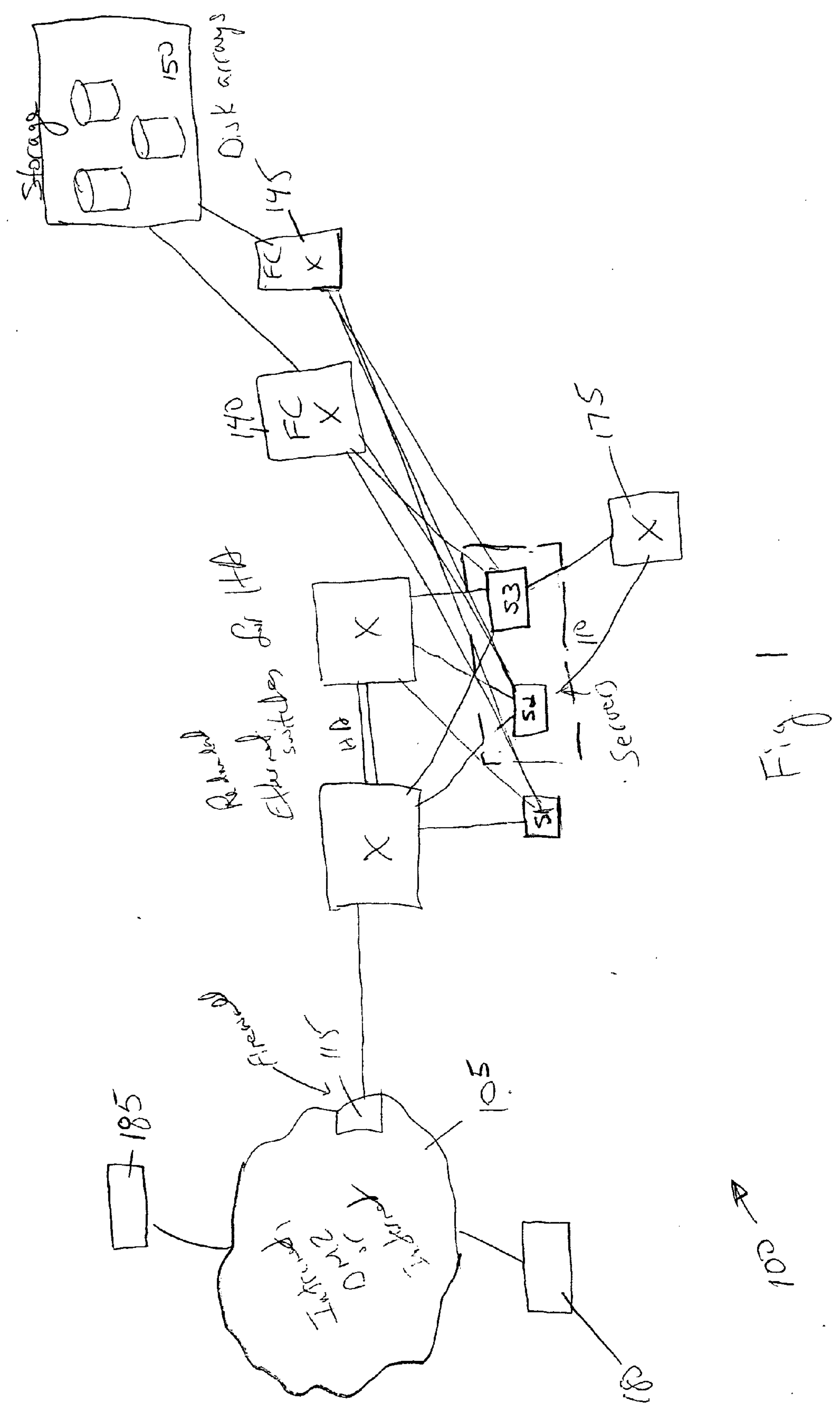

Storage
Disk arrays
150
145
FC
140
175
Servers
115
105
185
180
100

Fig. 1

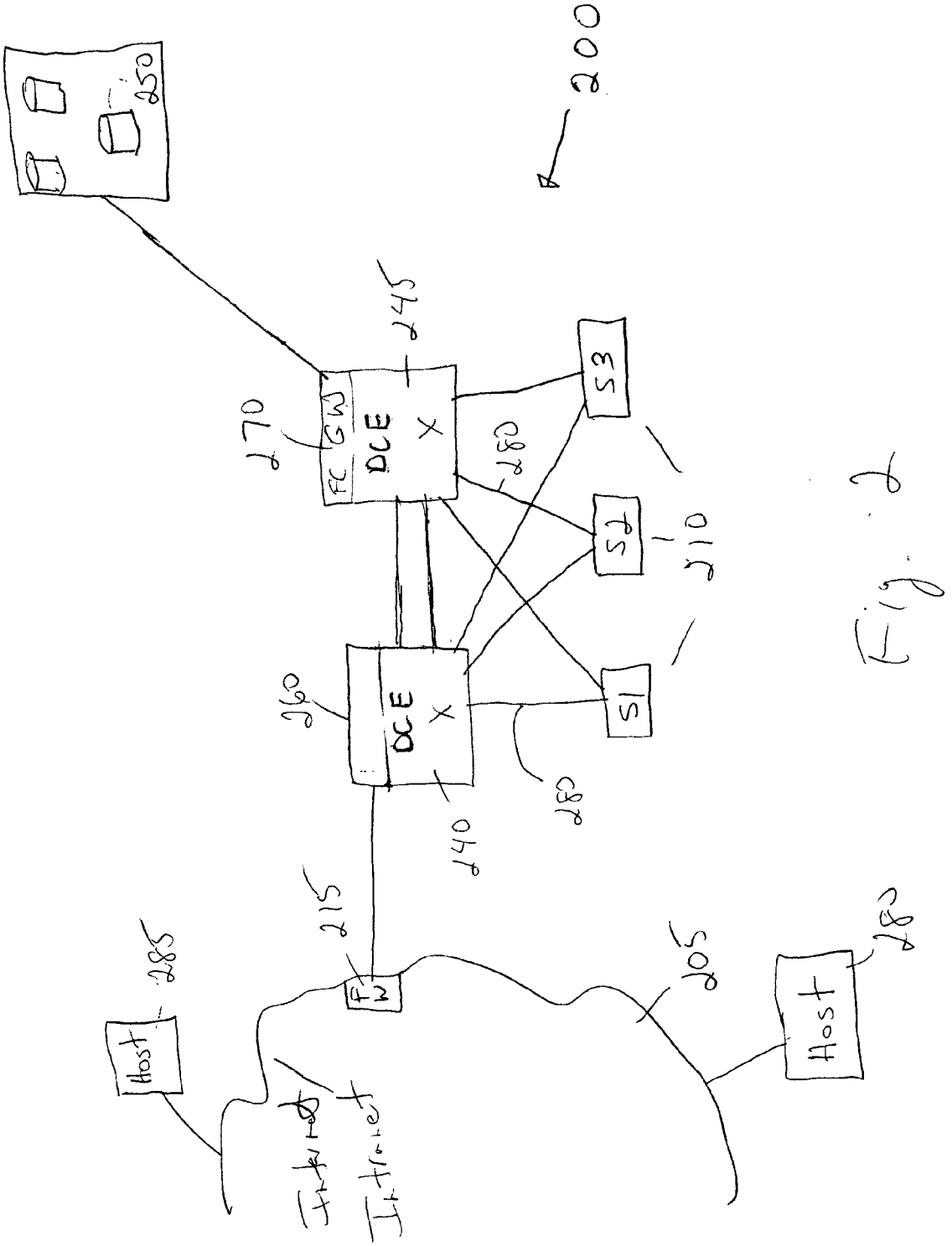

200
250
245
170
GW
FC
DCE
X
180
S3
S2
S1
210
190
DCE
X
S1
280
240
215
F2
285
Host
Interface
Interface
205
Host

Fig. 2

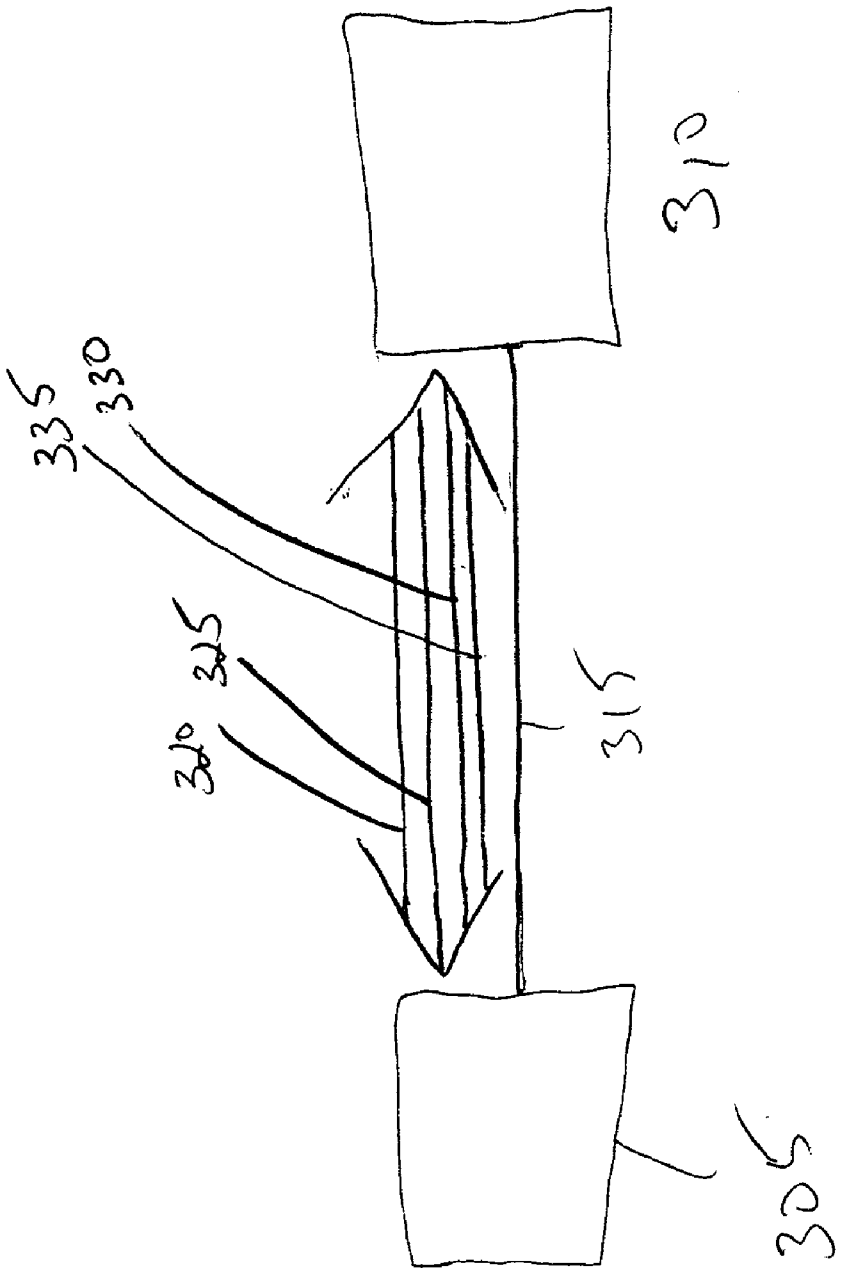


Fig. 3

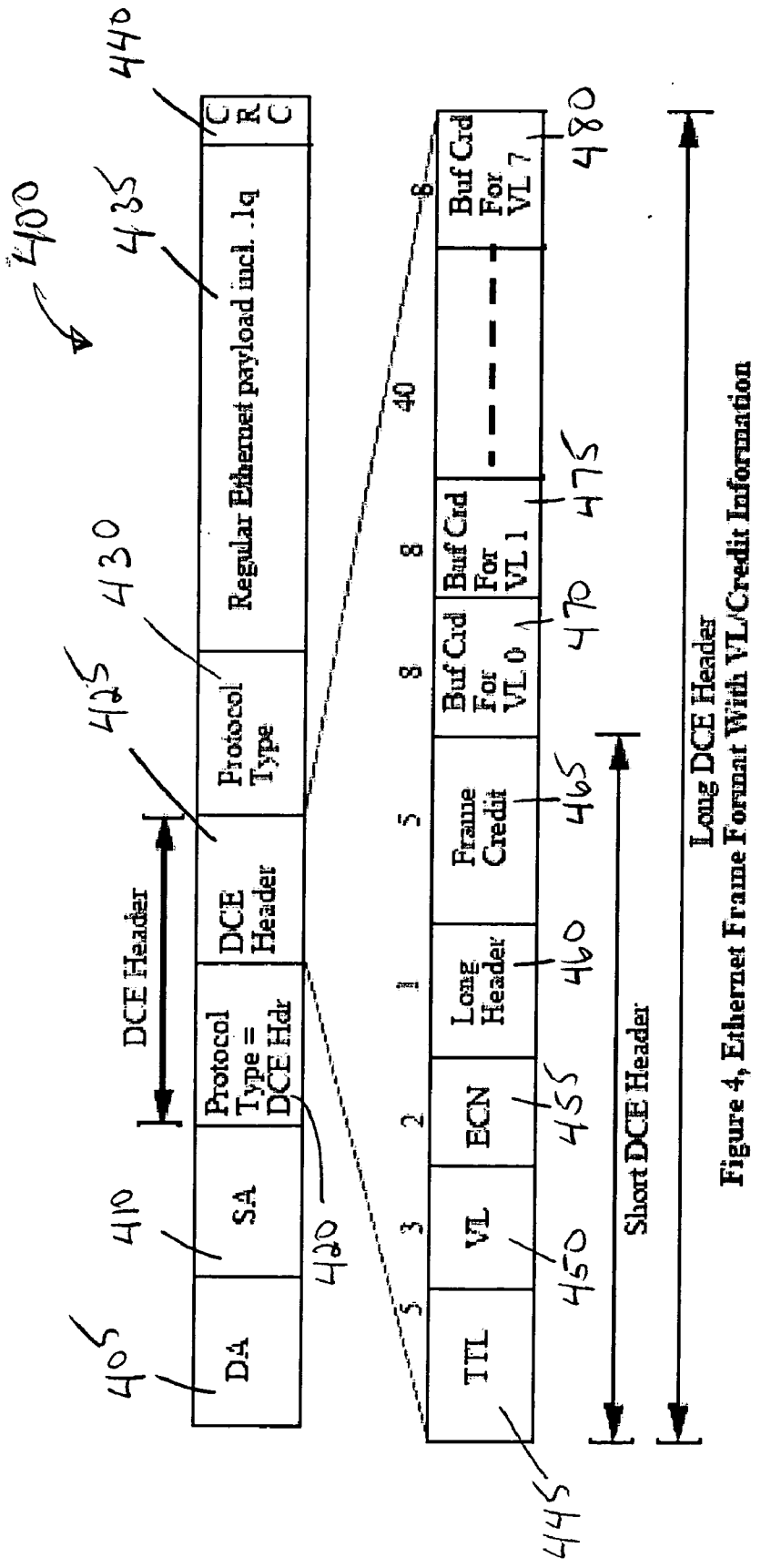


Figure 4, Ethernet Frame Format With VL/Credit Information

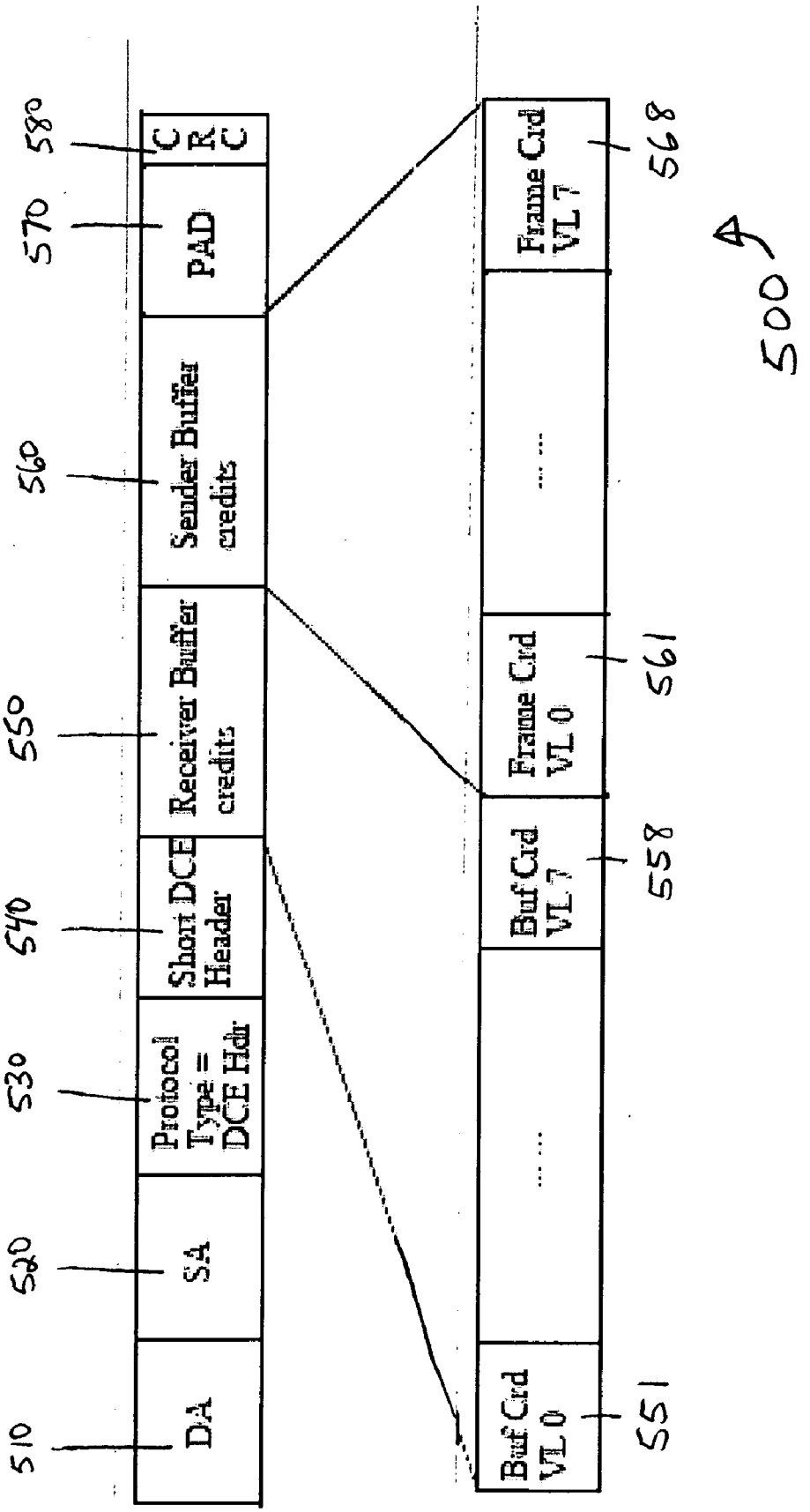

DA
SA
Protocol Type = DCE Hdr
Short DCE Header
Receiver Buffer credits
Sender Buffer credits
PAD
CRC
Buf Crd VL 0
.....
Buf Crd VL 7
Frame Crd VL 0
.....
Frame Crd VL 7
510
520
530
540
550
560
570
580
551
558
561
568
500

Fig. 5

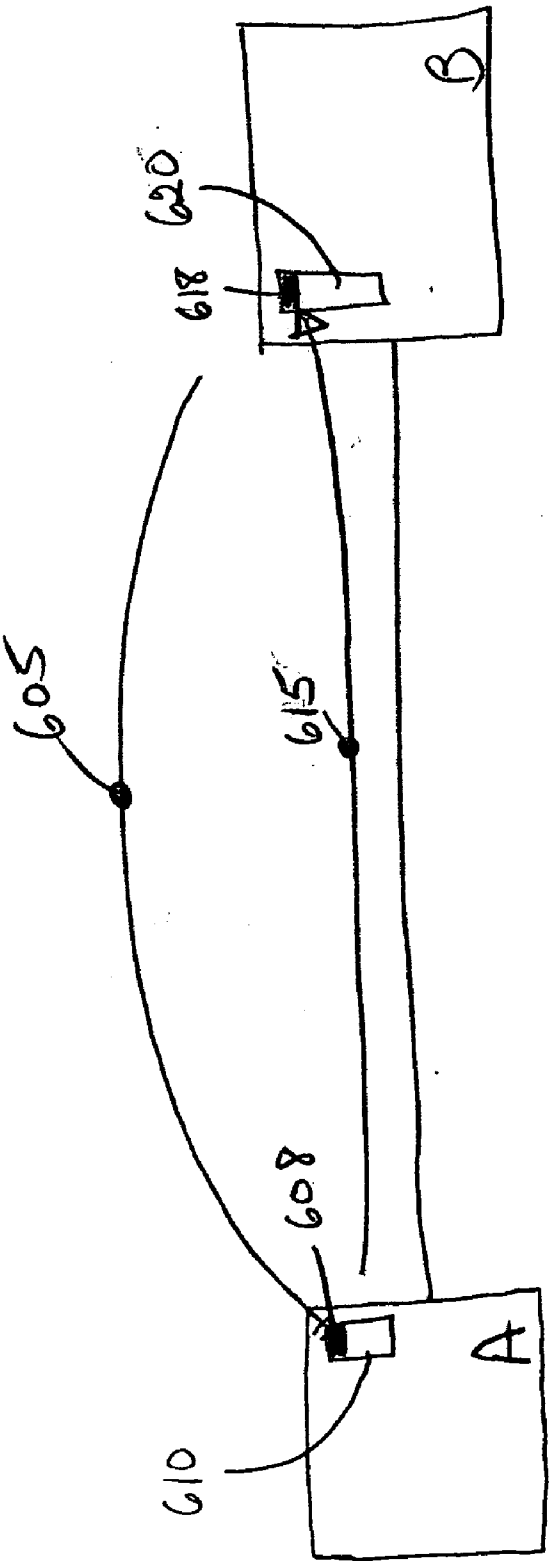


FIG 6A

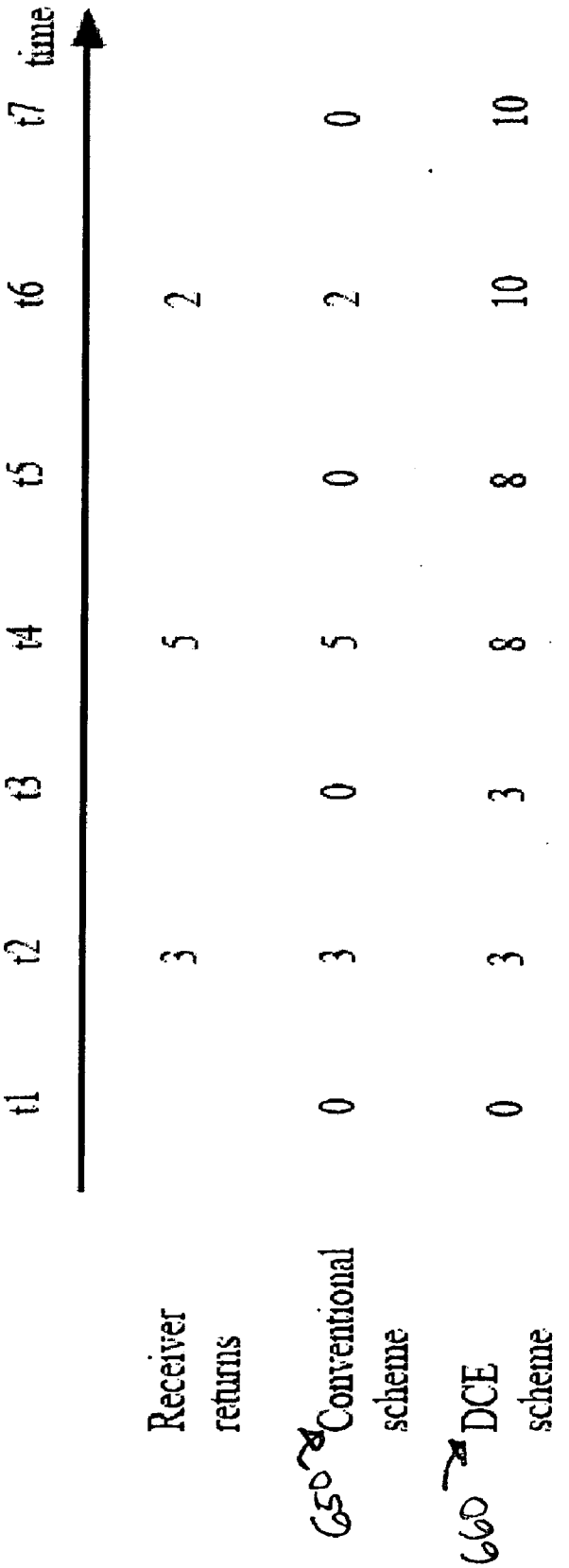

t1 t2 t3 t4 t5 t6 t7 time
Receiver returns
650 Conventional scheme
660 DCE scheme
0 3 0 5 0 2 0
0 3 3 8 8 10 10
3 5 2

Fig. 6B

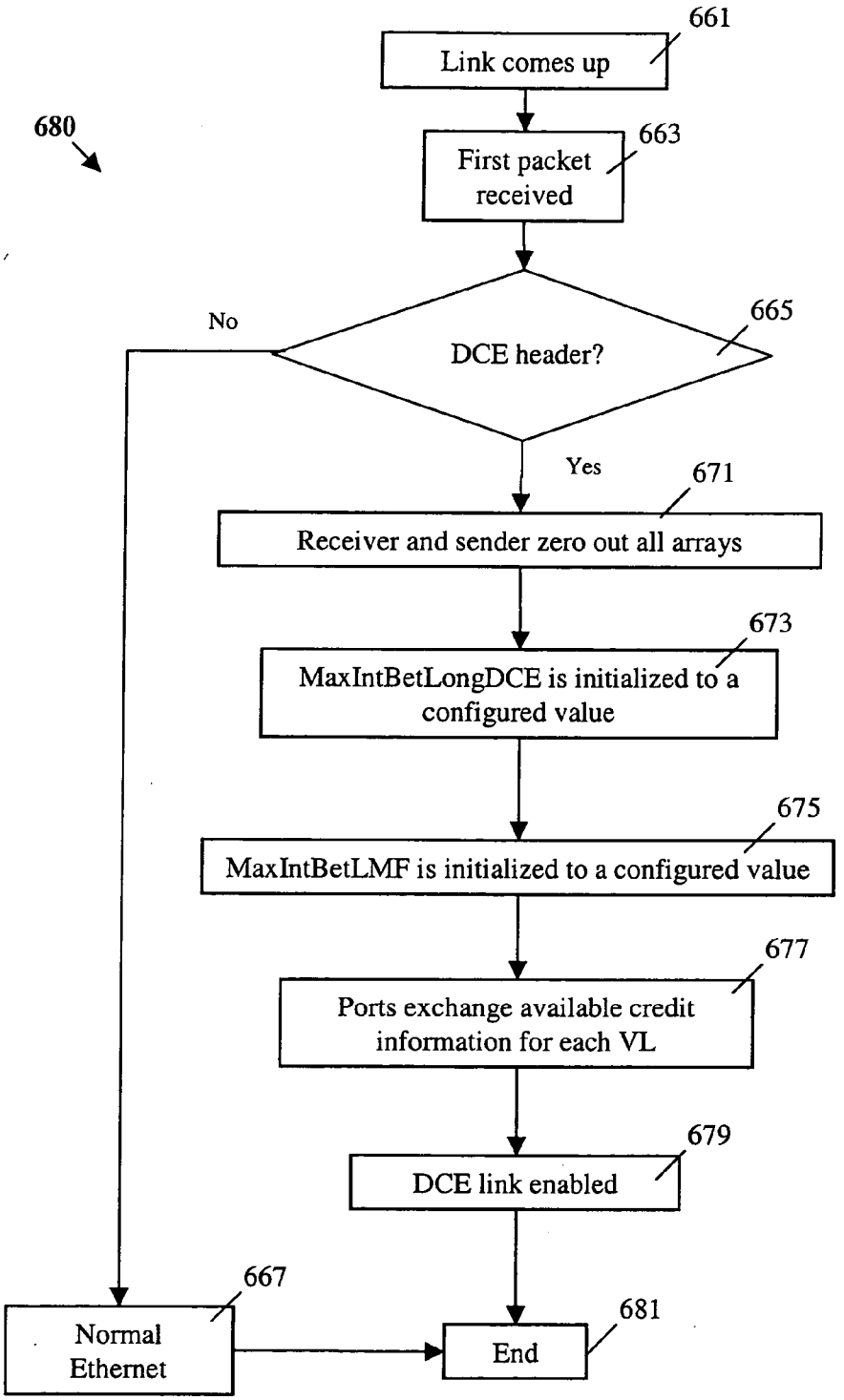

680
661
Link comes up
663
First packet received
665
DCE header?
No
Yes
671
Receiver and sender zero out all arrays
673
MaxIntBetLongDCE is initialized to a configured value
675
MaxIntBetLMF is initialized to a configured value
677
Ports exchange available credit information for each VL
679
DCE link enabled
667
Normal Ethernet
681
End

Fig. 6C

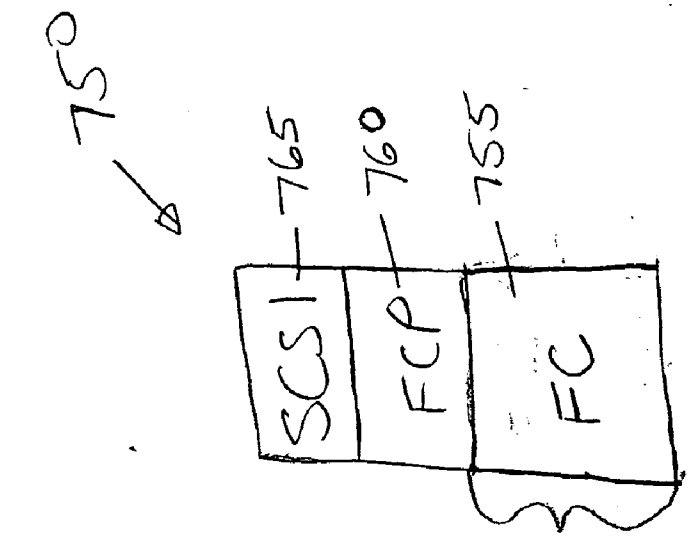

750
765
760
755
SCSI
FCP
FC

Fig 7B

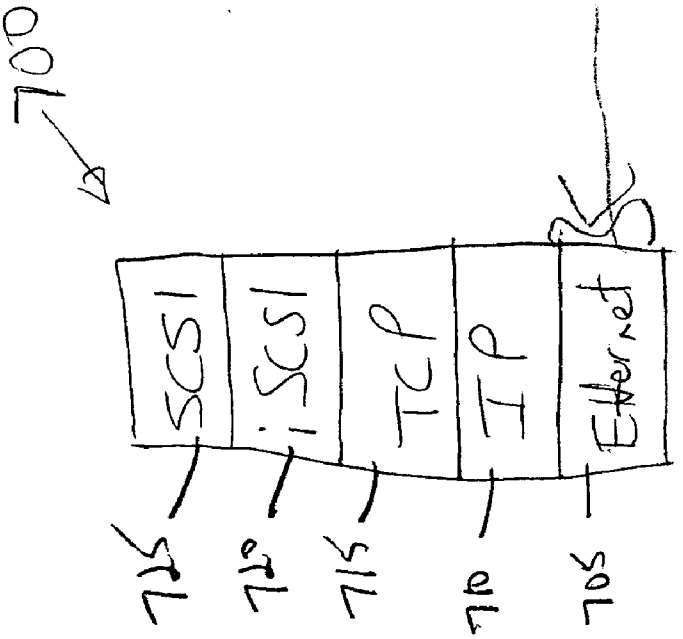

700
SCSI
iSCSI
TCP
IP
Ethernet
745
740
715
710
705

Fig. 7A

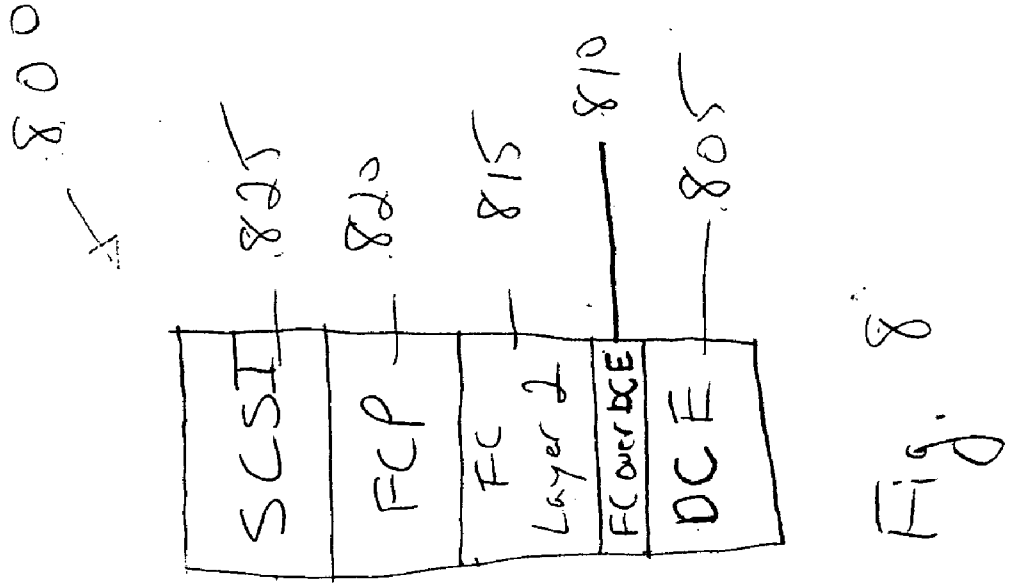


Fig. 8

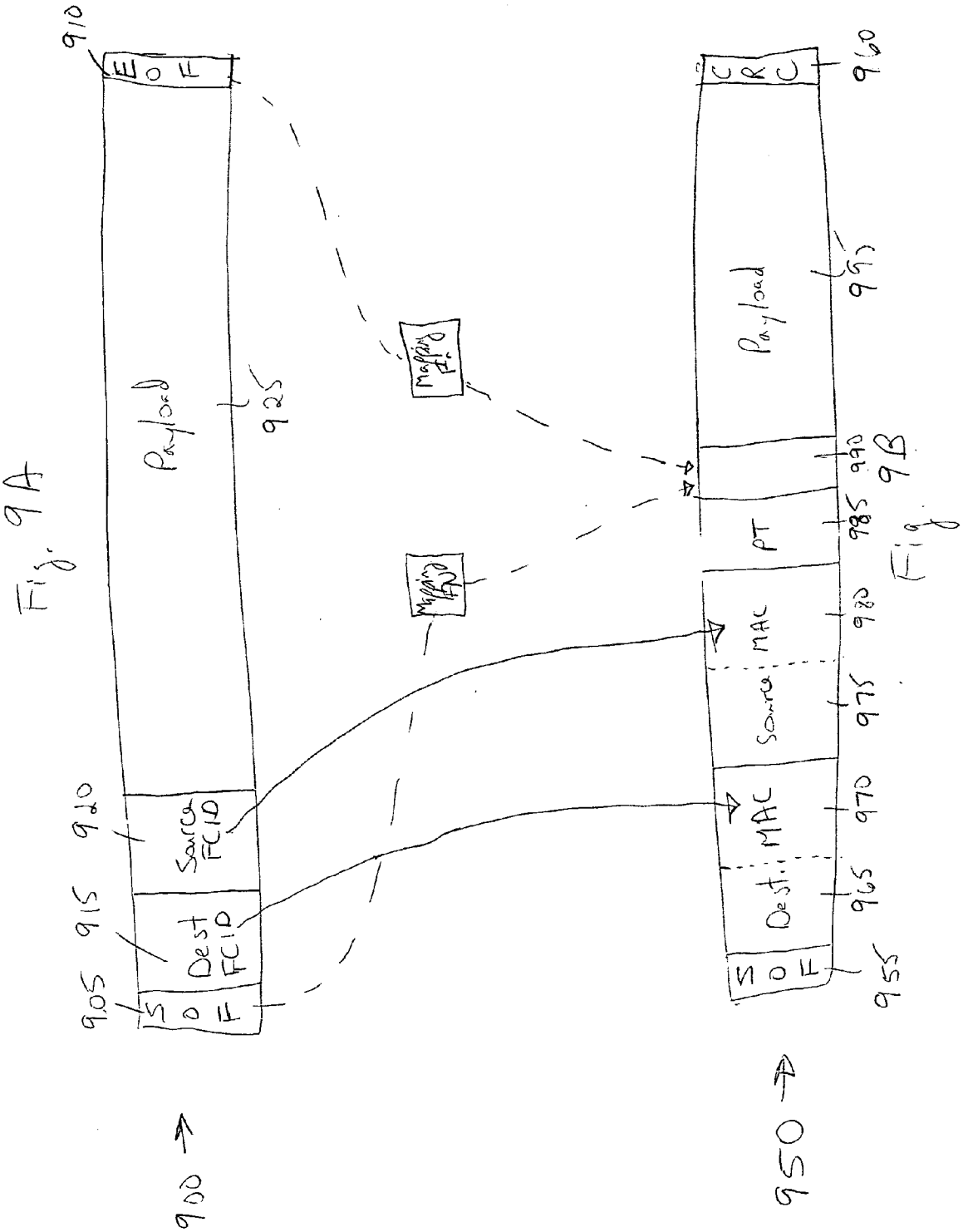

910
EOF
Payload
925
Source FCID
Dest FCID
915
905
SOF
900
Mapping
Mapping
CRC
960
Payload
965
990
PT
985
Source MAC
975
Dest. MAC
970
SOF
955
950

Fig. 9A

Fig. 9B

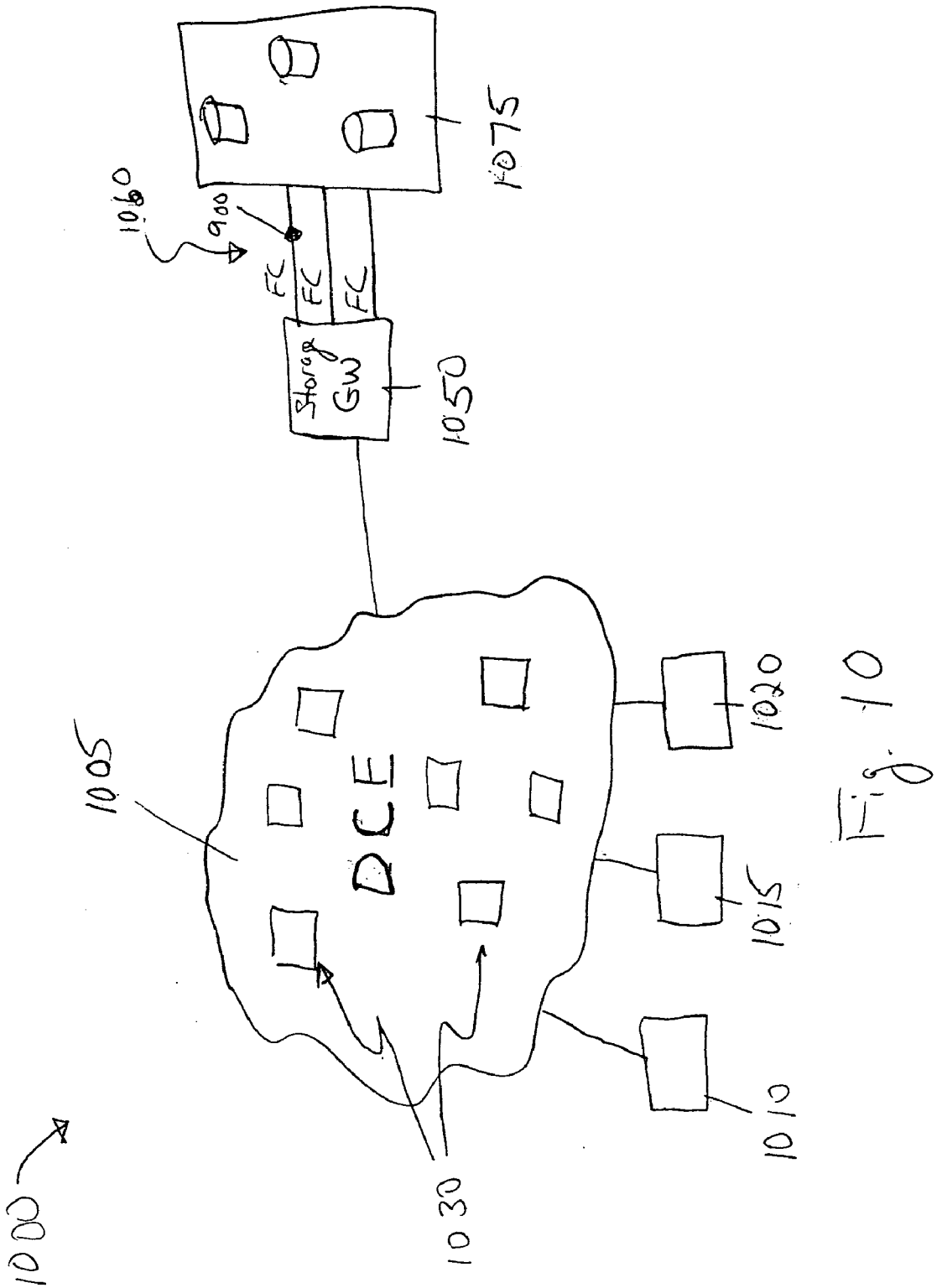
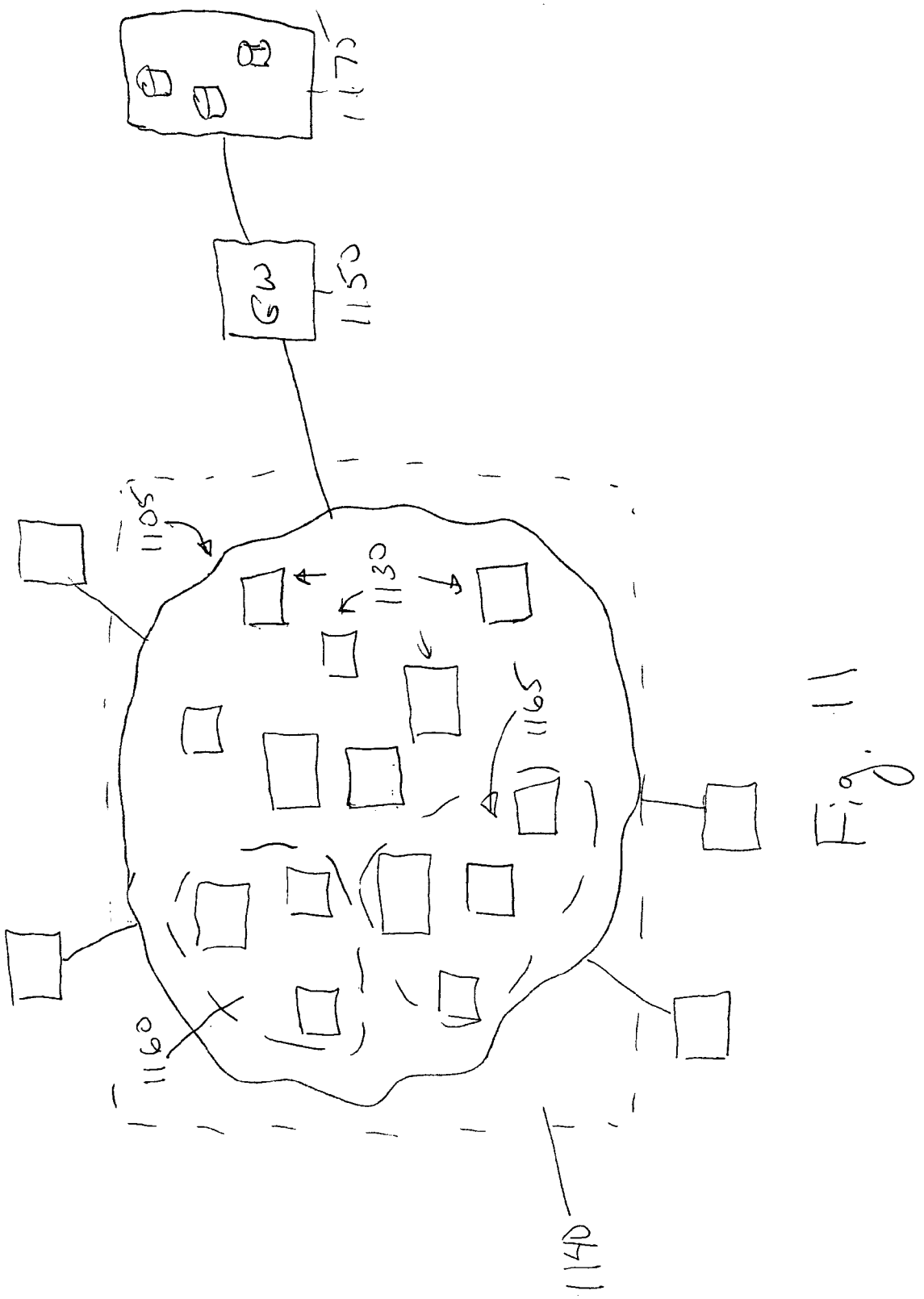

1075
1060
900
FC
FC
FC
Storage GW
1050
DCE
1005
1020
1015
1010
1030
1000

Fig. 10


1170
1150
1105
1130
1165
1110
1140

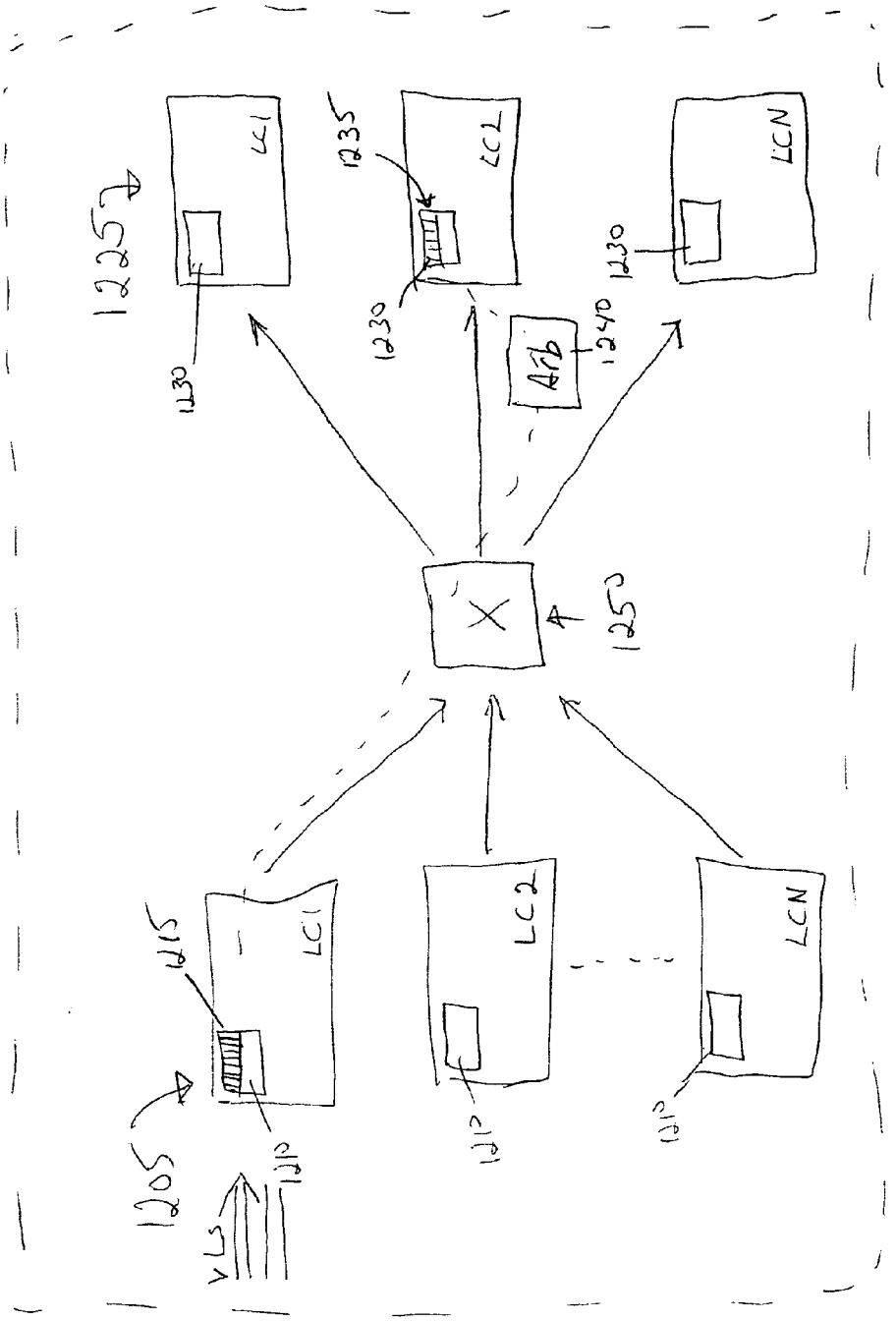
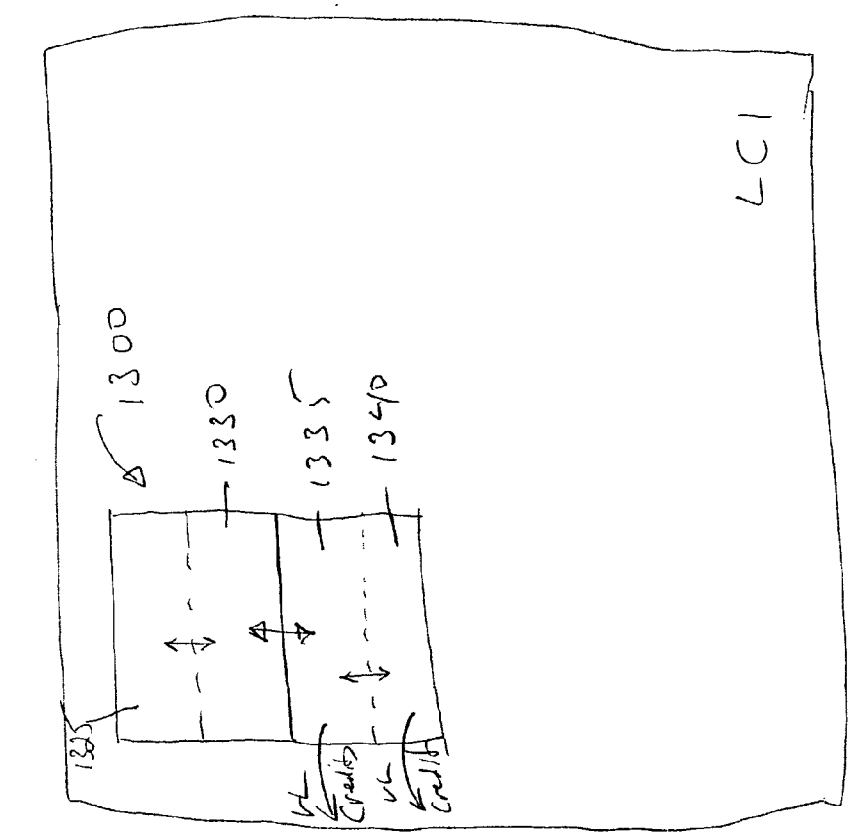

1225
LC1
1235
LC2
LCN
1230
1230
1230
ARB
1240
X
1250
LC1
1215
LC2
LCN
1205
1210
1210
1210
VLS
1200

Fig. 12


LCI
1300
1330
1335
1340
1325
Credits
Credits

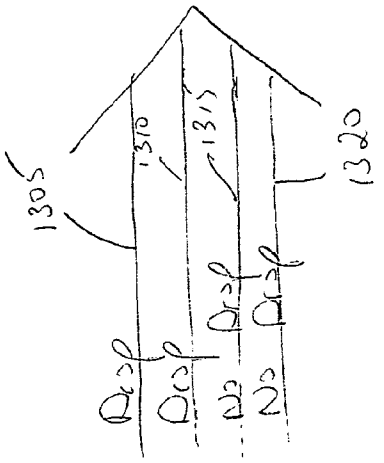

1305
1310
1315
1320

Fig. 13

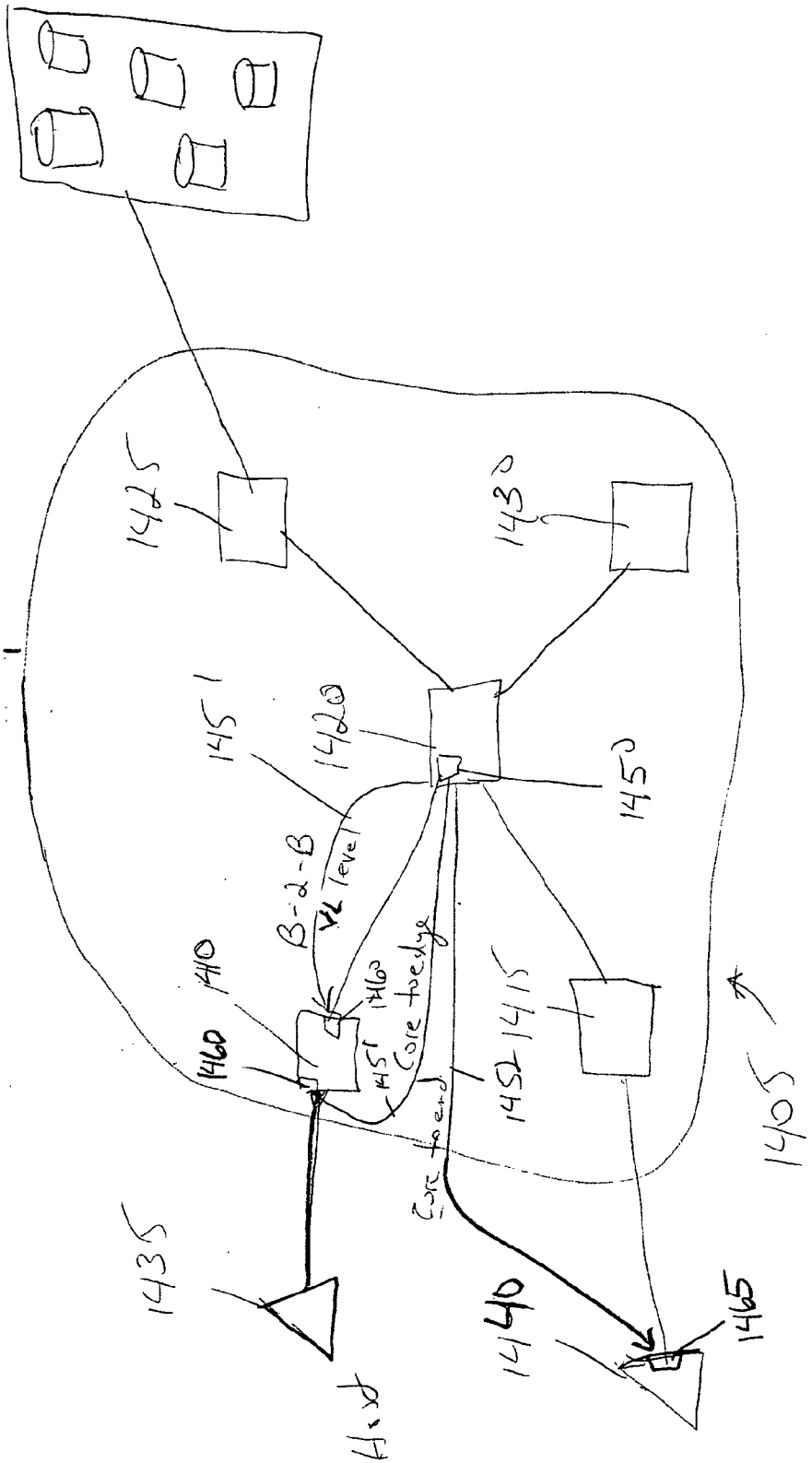

1425
1430
1451
1420
B-2-B level
VL
1460
1410
1460
1452
1415
Core to edge
1405
1435
1440
1465

Fig. 14

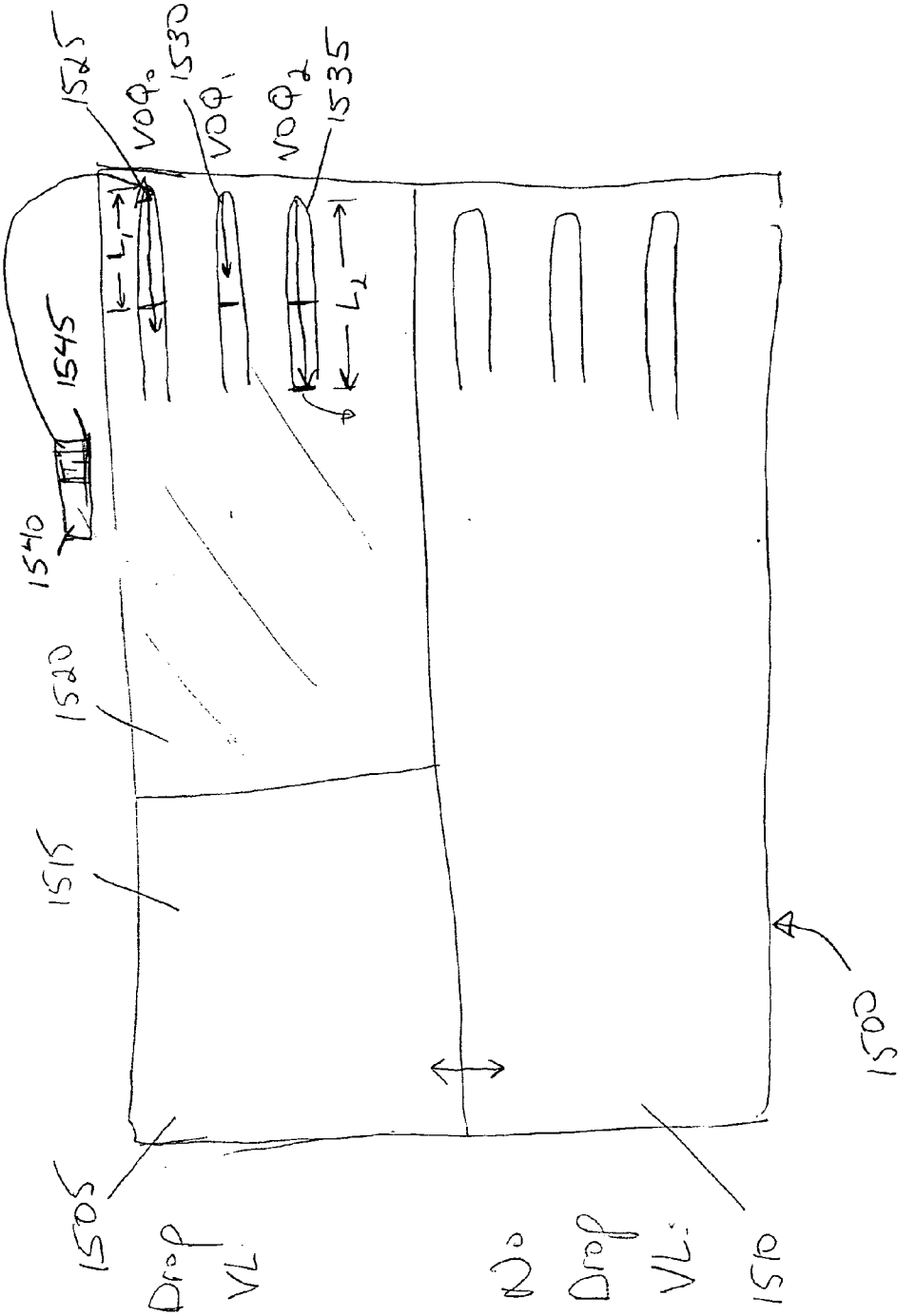

1525
VOQ0
1530
VOQ1
VOQ2
1535
L1
L2
1545
1540
1520
1515
1500
1505
Drop
VL
2°
Drop
VL
1510

Fig. 15

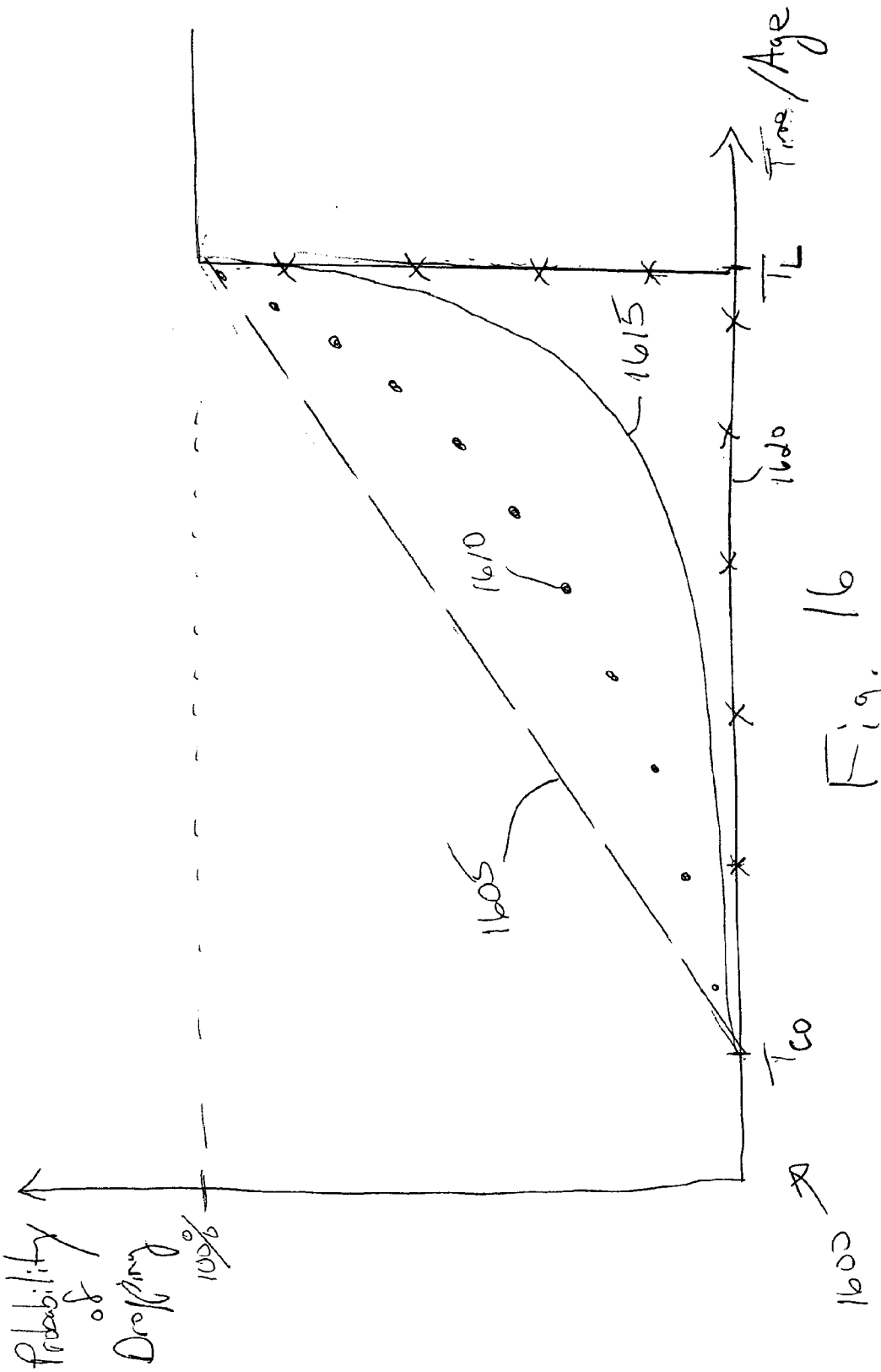

Probability of Drilling
100%
Time / Age
T_L
T_{CO}
1600
1605
1610
1615
1620

Fig. 16

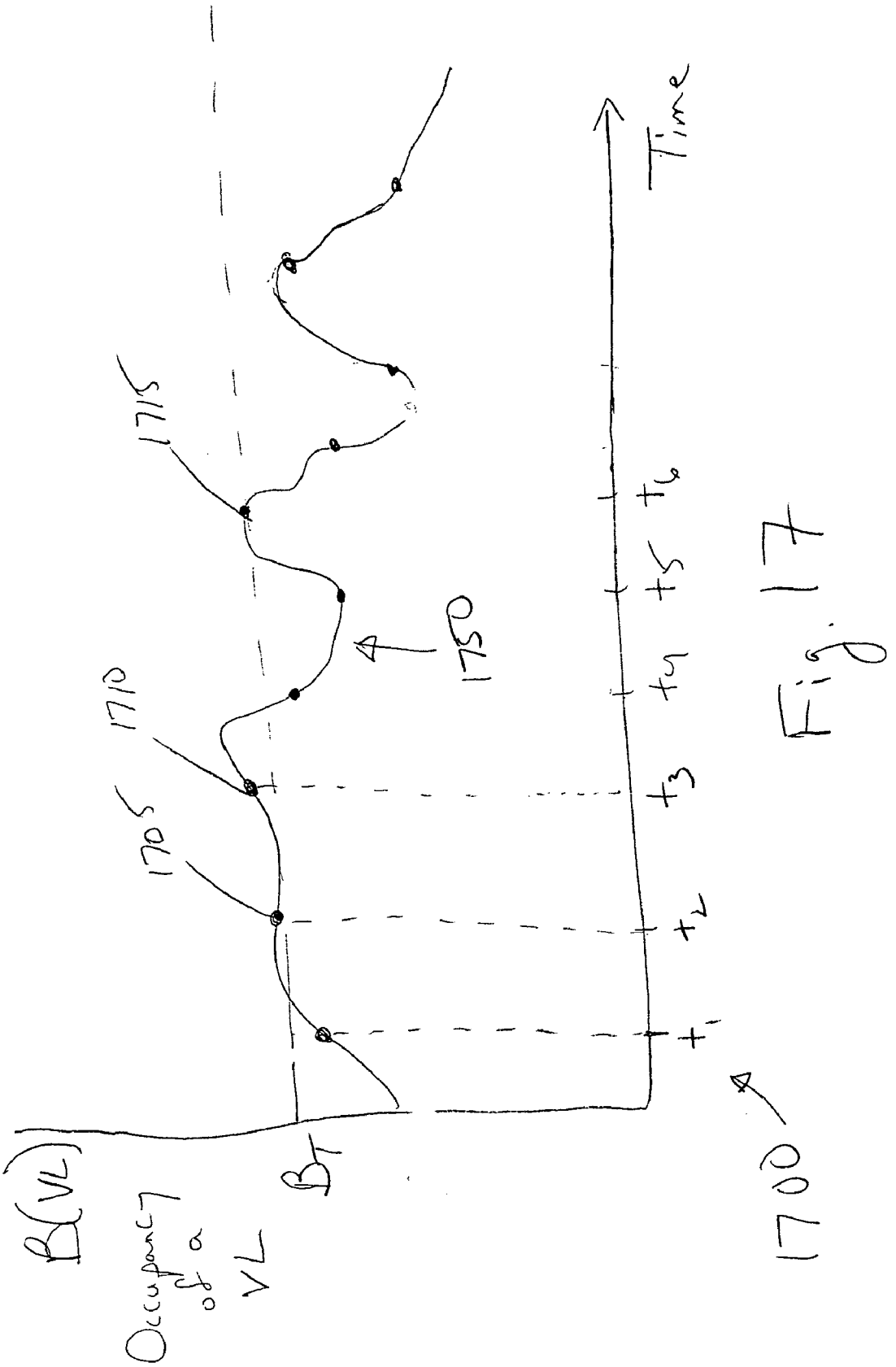

B(VL)
Occupancy of a VL
B_T
Time
t_1
t_2
t_3
t_4
t_5
t_6
1700
1705
1710
1715
1750

Fig. 17

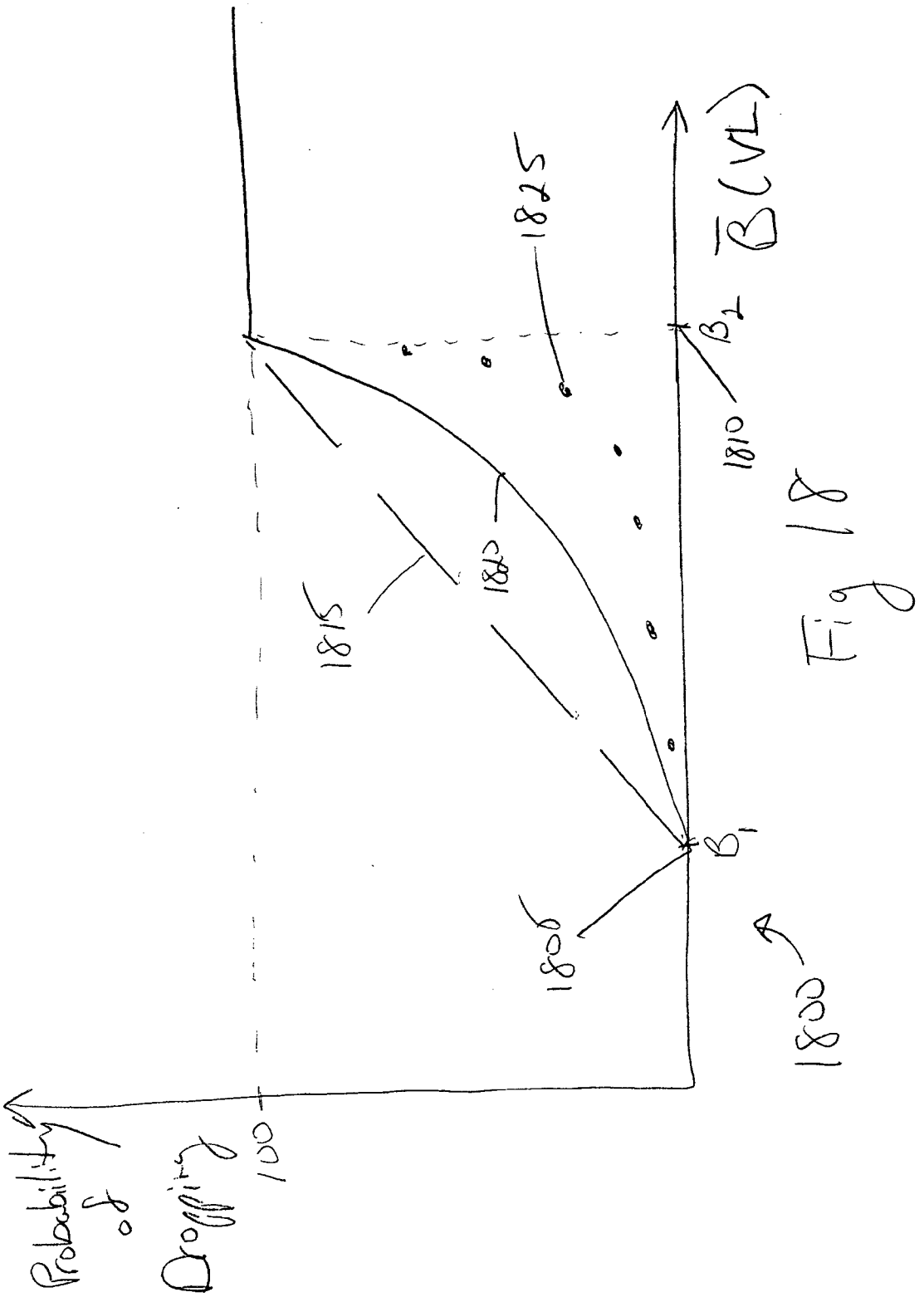

Probability of Dropping
100
1800
1805
1810
1815
1820
1825
B1
B2
B (VL)
1830

Fig 18

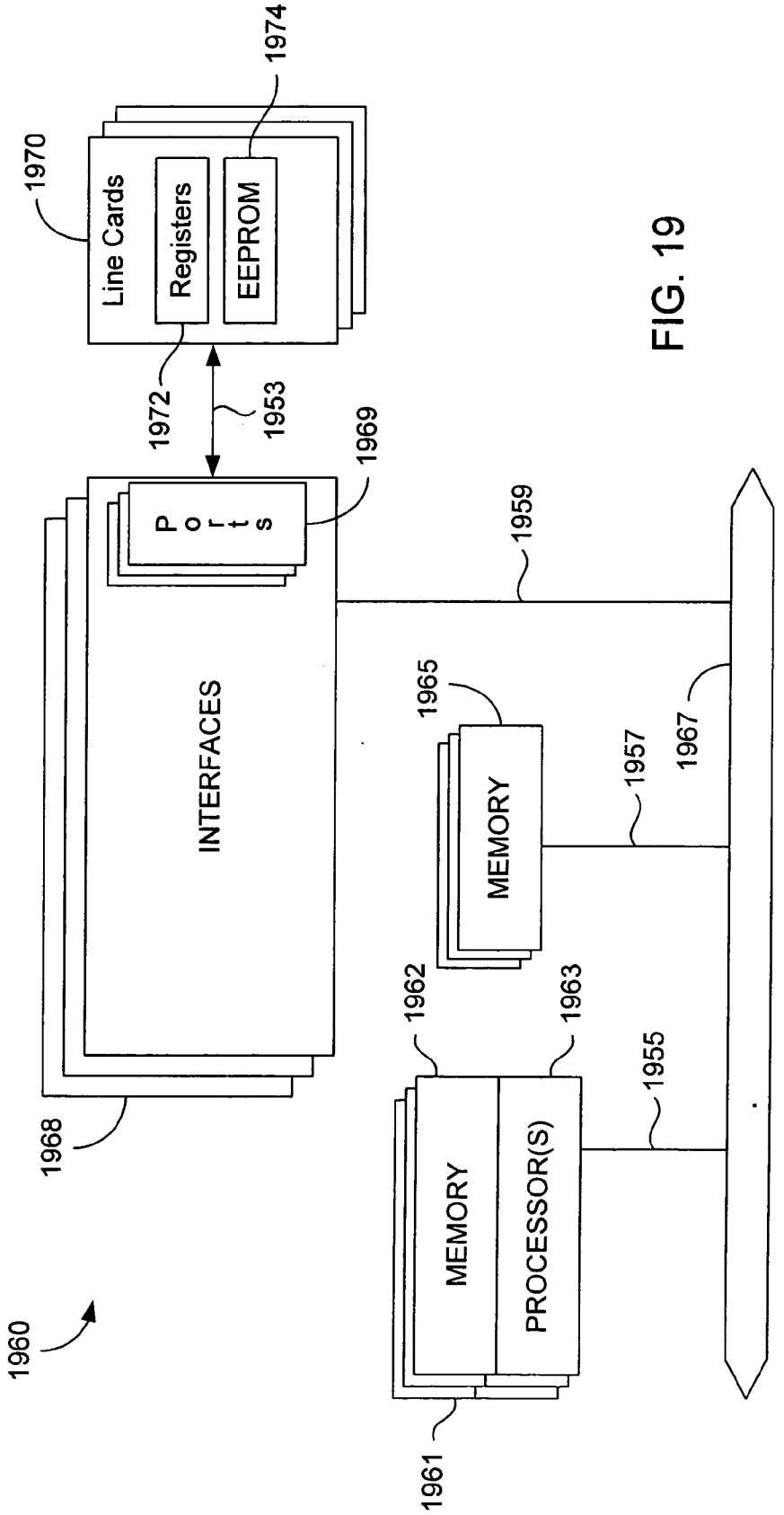

1974
1970
Line Cards
Registers
EEPROM
1972
1953
1969
Ports
1959
INTERFACES
1965
MEMORY
1957
1967
1962
1963
1955
MEMORY
PROCESSOR(S)
1968
1960
1961

FIG. 19

ETHERNET EXTENSION FOR THE DATA CENTER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 60/621,396 (Attorney Docket No. CISCP404P), entitled "FC Over Ethernet" and filed on Oct. 22, 2004, which is hereby incorporated by reference in its entirety. This application is related to U.S. patent application Ser. No. _____ (Attorney Docket No. CISCP409), entitled "Fibre Channel Over Ethernet" and filed on Mar. 10, 2005, which is also hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] **FIG. 1** depicts a simplified version of a data center of the general type that an enterprise that requires high availability and network storage (e.g., a financial institution) might use. Data center **100** includes redundant Ethernet switches with redundant connections for high availability. Data center **100** is connected to clients via network **105** via a firewall **115**. Network **105** may be, e.g., an enterprise Intranet, a DMZ and/or the Internet. Ethernet is well suited for TCP/IP traffic between clients (e.g., remote clients **180** and **185**) and a data center.

[0003] Within data center **105**, there are many network devices. For example, many servers are typically disposed on racks having a standard form factor (e.g., one "rack unit" would be 19" wide and about 1.25" thick). A "Rack Unit" or "U" is an Electronic Industries Alliance (or more commonly "EIA") standard measuring unit for rack mount type equipment. This term has become more prevalent in recent times due to the proliferation of rack mount products showing up in a wide range of commercial, industrial and military markets. A "Rack Unit" is equal to 1.75" in height. To calculate the internal useable space of a rack enclosure you would simply multiply the total amount of Rack Units by 1.75". For example, a 44 U rack enclosure would have 77" of internal usable space (44×1.75). Racks within a data center may have, e.g., about 40 servers each. A data center may have thousands of servers, or even more. Recently, some vendors have announced "blade servers," which allow even higher-density packing of servers (on the order of 60 to 80 servers per rack).

[0004] However, with the increasing numbers of network devices within a data center, connectivity has become increasingly complex and expensive. At a minimum, the servers, switches, etc., of data center **105** will typically be connected via an Ethernet. For high availability, there will be at least 2 Ethernet connections, as shown in **FIG. 1**.

[0005] Moreover, it is not desirable for servers to include a significant storage capability. For this reason and other reasons, it has become increasingly common for enterprise networks to include connectivity with storage devices such as storage array **150**. Historically, storage traffic has been implemented over SCSI (Small Computer System Interface) and/or FC (Fibre Channel).

[0006] In the mid-1990's SCSI traffic was only able to go short distances. A topic of key interest at the time was how to make SCSI go "outside the box." Greater speed, as always, was desired. At the time, Ethernet was moving from 10 Mb/s to 100 Mb/s. Some envisioned a future speed of up to 1 Gb/s, but this was considered by many to be nearing a physical limit. With 10 Mb/s Ethernet, there were the issues of half duplex and of collisions. Ethernet was considered to be somewhat unreliable, in part because packets could be lost and because there could be collisions. (Although the terms "packet" and "frame" have somewhat different meanings as normally used by those of skill in the art, the terms will be used interchangeably herein.) FC was considered to be an attractive and reliable option for storage applications, because under the FC protocol packets are not intentionally dropped and because FC could already be run at 1 Gb/s. However, during 2004, both Ethernet and FC reached speeds of 10 Gb/s. Moreover, Ethernet had evolved to the point that it was full duplex and did not have collisions. Accordingly, FC no longer had a speed advantage over Ethernet. However congestion in a switch may cause Ethernet packets to be dropped and this is an undesirable feature for storage traffic.

[0007] During the first few years of the 21st century, a significant amount of work went into developing iSCSI, in order to implement SCSI over a TCP/IP network. Although these efforts met with some success, iSCSI has not become very popular: iSCSI has about 1%-2% of the storage network market, as compared to approximately 98%-99% for FC.

[0008] One reason is that the iSCSI stack is somewhat complex as compared to the FC stack. Referring to **FIG. 7A**, it may be seen that iSCSI stack **700** requires 5 layers: Ethernet layer **705**, IP layer **710**, TCP layer **715**, iSCSI layer **720** and SCSI layer **725**. TCP layer **715** is a necessary part of the stack because Ethernet layer **705** may lose packets, but yet SCSI layer **725** does not tolerate packets being lost. TCP layer **715** provides SCSI layer **725** with reliable packet transmission. However, TCP layer **715** is a difficult protocol to implement at speeds of 1 to 10 Gb/s. In contrast, because FC does not lose frames, there is no need to compensate for lost frames by a TCP layer or the like. Therefore, as shown in **FIG. 7B**, FC stack **750** is simpler, requiring only FC layer **755**, FCP layer **760** and SCSI layer **765**.

[0009] Accordingly, the FC protocol is normally used for communication between servers on a network and storage devices such as storage array **150**. Therefore, data center **105** includes FC switches **140** and **145**, provided by Cisco Systems, Inc. in this example, for communication between servers **110** and storage array **150**.

[0010] 1 RU and Blade Servers are very popular because they are relatively inexpensive, powerful, standardized and can run any of the most popular operating systems. It is well known that in recent years the cost of a typical server has decreased and its performance level has increased. Because of the relatively low cost of servers and the potential problems that can arise from having more than one type of software application run on one server, each server is typically dedicated to a particular application. The large number of applications that is run on a typical enterprise network continues to increase the number of servers in the network.

[0011] However, because of the complexities of maintaining various types of connectivity (e.g., Ethernet and FC connectivity) with each server, each type of connectivity preferably being redundant for high availability, the cost of connectivity for a server is becoming higher than the cost of

the server itself. For example, a single FC interface for a server may cost as much as the server itself. A server's connection with an Ethernet is typically made via a network interface card ("NIC") and its connection with an FC network is made with a host bus adaptor ("HBA").

[0012] The roles of devices in an FC network and a Ethernet network are somewhat different with regard to network traffic, mainly because packets are routinely dropped in response to congestion in a TCP/IP network, whereas frames are not intentionally dropped in an FC network. Accordingly, FC will sometimes be referred to herein as one example of a "no-drop" network, whereas Ethernet will be referred to as one manifestation of a "drop" network. When packets are dropped on a TCP/IP network, the system will recover quickly, e.g., in a few hundred microseconds. However, the protocols for an FC network are generally based upon the assumption that frames will not be dropped. Therefore, when frames are dropped on an FC network, the system does not recover quickly and SCSI may take minutes to recover.

[0013] Currently, a port of an Ethernet switch may buffer a packet for up to about **100** milliseconds before dropping it. As 10 Gb/s Ethernet is implemented, each port of an Ethernet switch would need approximately 100 MB of RAM in order to buffer a packet for 100 milliseconds. This would be prohibitively expensive.

[0014] For some enterprises, it is desirable to "cluster" more than one server, as indicated by the dashed line around servers **S2** and **S3** in **FIG. 1**. Clustering causes an even number of servers to be seen as a single server. For clustering, it is desirable to perform remote direct memory access ("RDMA"), wherein the contents of one virtual memory space (which may be scattered among many physical memory spaces) can be copied to another virtual memory space without CPU intervention. The RDMA should be performed with very low latency. In some enterprise networks, there is a third type of network that is dedicated to clustering servers, as indicated by switch **175**. This may be, for example, a "Myrinet," a "Quadrix" or an "Infiniband" network.

[0015] Therefore, clustering of servers can add yet more complexity to data center networks. However, unlike Quadrix and Myrinet, Infiniband allows for clustering and provides the possibility of simplifying a data center network. Infiniband network devices are relatively inexpensive, mainly because they use small buffer spaces, copper media and simple forwarding schemes.

[0016] However, Infiniband has a number of drawbacks. For example, there is currently only one source of components for Infiniband switches. Moreover, Infiniband has not been proven to work properly in the context of, e.g., a large enterprise's data center. For example, there are no known implementations of Infiniband routers to interconnect Infiniband subnets. While gateways are possible between Infiniband and Fibre Channel and Infiniband to Ethernet, it is very improbable that Ethernet will be removed from the datacenter. This also means that the hosts would need not only an Infiniband connection, but also an Ethernet connection.

[0017] Accordingly, even if a large enterprise wished to ignore the foregoing shortcomings and change to an Infiniband-based system, the enterprise would need to have a legacy data center network (e.g., as shown in **FIG. 1**) installed and functioning while the enterprise tested an Infiniband-based system. Therefore, the cost of an Infiniband-based system would not be an alternative cost, but an additional cost.

[0018] It would be very desirable to simplify data center networks in a manner that would allow an evolutionary change from existing data center networks. An ideal system would provide an evolutionary system for consolidating server I/O and providing low latency and high speed at a low cost.

SUMMARY OF THE INVENTION

[0019] The present invention provides methods and devices for implementing a Low Latency Ethernet ("LLE") solution, also referred to herein as a Data Center Ethernet ("DCE") solution, which simplifies the connectivity of data centers and provides a high bandwidth, low latency network for carrying Ethernet and storage traffic. Some aspects of the invention involve transforming FC frames into a format suitable for transport on an Ethernet. Some preferred implementations of the invention implement multiple virtual lanes ("VLs") (also referred to as virtual links) in a single physical connection of a data center or similar network. Some VLs are "drop" VLs, with Ethernet-like behavior, and others are "no-drop" lanes with FC-like behavior.

[0020] A VL may be implemented, in part, by tagging a frame. Because each VL may have its own credits, each VL may be treated independently from other VLs. We can even determine the performance of each VL according to the credits assigned to the VL, according to the replenishment rate. To allow a more complex topology and to allow better management of a frame inside a switch, TTL information may be added to a frame as well as a frame length field. There may also be encoded information regarding congestion, so that a source may receive an explicit message to slow down.

[0021] Some preferred implementations of the invention provide guaranteed bandwidth based on credits and VL. Different VLs may be assigned different guaranteed bandwidths that can change over time. Preferably, a VL will remain a drop or no drop lane, but the bandwidth of the VL may be dynamically changed depending on the time of day, tasks to be completed, etc.

[0022] Active buffer management allows for both high reliability and low latency while using small frame buffers, even with 10 GB/s Ethernet. Preferably, the rules for active buffer management are applied differently for drop and no drop VLs. Some embodiments of the invention are implemented with copper media instead of fiber optics. Given all these attributes, I/O consolidation may be achieved in a competitive, relatively inexpensive fashion.

[0023] Some aspects of the invention provide a method for carrying more than one type of traffic on a single physical link. The method includes these steps: logically partitioning traffic on a physical link into a plurality of virtual lanes; applying a first set of rules to first traffic on a first virtual lane; and applying a second set of rules to second traffic on a second virtual lane. However, some implementations of the invention involve more than two virtual lanes. Accordingly, the method can include the steps of applying third through Nth sets of rules to traffic on third through Nth virtual lanes.

[0024] The method can include the step of differentiating service per virtual lane. As used herein, the term "differentiating service" or the like means causing service to differ based on factors that include, but are not limited to, guaranteed minimum bandwidth and/or other indicia of quality of service ("QoS"), access control and other related security measures, etc.

[0025] The traffic carried on the virtual lanes may be, for example, Ethernet traffic, storage traffic and/or some form of Inter Process Communication ("IPC") traffic, including but not limited to cluster or inter-cluster traffic such as RDMA traffic.

[0026] In some implementations of the method, the first set of rules causes frames to be dropped in response to latency but the second set of rules does not cause frames to be dropped in response to latency. However, the second set of rules may nonetheless cause frames to be dropped in order to avoid deadlocks. The rules may apply a probabilistic drop function in response to latency.

[0027] The first and/or the second set of rules may cause an explicit congestion notification to be transmitted in response to latency. The explicit congestion notification may be sent to a source device or an edge device and may be sent via a data frame or a control frame.

[0028] The method may involve implementing flow control per virtual lane, e.g., by using one or more of a buffer-to-buffer crediting scheme and PAUSE frames. The buffer-to-buffer crediting scheme may involve crediting according frame size or by a number of frames (e.g., on a frame-by-frame basis). The buffer-to-buffer credits may be indicated via one of a data frame or a control frame.

[0029] Alternative aspects of the invention provide another method of transporting a plurality of traffic types on a single virtual link. The method includes these steps: receiving a first frame on a physical link; inspecting one or more fields of the first frame; determining, based on the one or more fields, that first virtual lane rules should apply to the first frame; and applying the first virtual lane rules to the first frame.

[0030] The method may also include these steps: receiving a second frame on a physical link; inspecting one or more fields of the second frame; determining, based on the one or more fields, that second virtual lane rules should apply to the second frame; and applying the second virtual lane rules to the second frame. The first virtual lane rules may include a first set of active buffer management rules and wherein the second virtual lane rules may include a second set of active buffer management rules. The first virtual lane rules and the second virtual lane rules may differentiate service per virtual lane.

[0031] The determining step may involve parsing explicit or implicit virtual lane identification information. The determining step may involve mapping implicit virtual lane identification information with a corresponding virtual lane. For example, the VLAN-ID space may be partitioned into virtual lanes, with and each VLAN belonging to a single virtual lane. By parsing the VLAN-ID in a frame, the corresponding virtual lane ID may be determined.

[0032] Other methods of transporting a plurality of traffic types on a single virtual link are provided by the present invention. One such method involves initializing a physical link between a first switch port and a second switch port and determining whether the frame contains information required for establishing virtual lanes on the physical link. The method may already include the step of logically partitioning traffic on the physical link into a plurality of virtual lanes when it is determined that the frame contains information required for establishing virtual lanes on the physical link. The method may also include the step of establishing a standard Ethernet connection on the physical link when it is determined that the frame does not contain information required for establishing virtual lanes on the physical link.

[0033] Some embodiments of the invention provide a network device. The network device includes a plurality of ports, each port configured for communication on one of a plurality of physical links. The network device also includes a plurality of line cards. Each line card is configured to do the following: logically partition traffic on a physical link into a plurality of virtual lanes; apply a first set of rules to first traffic on a first virtual lane; and apply a second set of rules to second traffic on a second virtual lane.

[0034] The methods described herein may be implemented and/or manifested in various ways, including as hardware, software or the like.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings, which are illustrative of specific implementations of the present invention.

[0036] **FIG. 1** is a simplified network diagram that depicts a data center.

[0037] **FIG. 2** is a simplified network diagram that depicts a data center according to one embodiment of the invention.

[0038] **FIG. 3** is a block diagram that depicts multiple VLs implemented across a single physical link.

[0039] **FIG. 4** illustrates one format of an Ethernet frame that carries additional fields for implementing DCE according to some implementations of the invention.

[0040] **FIG. 5** illustrates one format of a link management frame according to some implementations of the invention.

[0041] **FIG. 6A** is a network diagram that illustrates a simplified credit-based method of the present invention.

[0042] **FIG. 6B** is a table that depicts a crediting method of the present invention.

[0043] **FIG. 6C** is a flow chart that outlines one exemplary method for initializing a link according to the present invention.

[0044] **FIG. 7A** depicts an iSCSI stack.

[0045] **FIG. 7B** depicts a stack for implementing SCSI over FC.

[0046] **FIG. 8** depicts a stack for implementing SCSI over DCE according to some aspects of the invention.

[0047] **FIGS. 9A and 9B** depicts a method for implementing FC over Ethernet according to some aspects of the invention.

[0048] **FIG. 10** is a simplified network diagram for implementing FC over Ethernet according to some aspects of the invention.

[0049] **FIG. 11** is a simplified network diagram for aggregating DCE switches according to some aspects of the invention.

[0050] **FIG. 12** depicts the architecture of a DCE switch according to some embodiments of the invention.

[0051] **FIG. 13** is a block diagram that illustrates buffer management per VL according to some implementations of the invention.

[0052] **FIG. 14** is a network diagram that illustrates some types of explicit congestion notification according to the present invention.

[0053] **FIG. 15** is a block diagram that illustrates buffer management per VL according to some implementations of the invention.

[0054] **FIG. 16** is a graph that illustrates probabilistic drop functions according to some aspects of the invention.

[0055] **FIG. 17** is a graph that illustrates an exemplary occupancy of a VL buffer over time.

[0056] **FIG. 18** is a graph that illustrates probabilistic drop functions according to alternative aspects of the invention.

[0057] **FIG. 19** illustrates a network device that may be configured to perform some methods of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0058] Reference will now be made in detail to some specific embodiments of the invention including the best modes contemplated by the inventors for carrying out the invention. Examples of these specific embodiments are illustrated in the accompanying drawings. While the invention is described in conjunction with these specific embodiments, it will be understood that it is not intended to limit the invention to the described embodiments. On the contrary, it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims. Moreover, numerous specific details are set forth below in order to provide a thorough understanding of the present invention. The present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to obscure the present invention.

[0059] The present invention provides methods and devices for simplifying the connectivity of data centers and providing a high bandwidth, low latency network for carrying Ethernet and storage traffic. Some preferred implementations of the invention implement multiple VLs in a single physical connection of a data center or similar network. Buffer-to-buffer credits are maintained, preferably per VL. Some VLs are "drop" VLs, with Ethernet-like behavior, and others are "no-drop" lanes with FC-like behavior.

[0060] Some implementations provide intermediate behaviors between "drop" and "no-drop." Some such implementations are "delayed drop," wherein frames are not immediately dropped when a buffer is full, but instead there is an upstream "push back" for a limited time (e.g., on the order of milliseconds) before dropping a frame. Delayed drop implementations are useful for managing transient congestion.

[0061] Preferably, a congestion control scheme is implemented at layer **2**. Some preferred implementations of the invention provide guaranteed bandwidth based on credits and VL. An alternative to the use of credits is the use of the standard IEEE 802.3 PAUSE frame per VL to implement the "no drop" or "delayed drop" VLs. The IEEE 802.3 standard is hereby incorporated by reference for all purposes. For example, Annex **31**B of the 802.3ae-2002 standard, entitled "MAC Control PAUSE Operation," is specifically incorporated by reference. It is also understood that this invention will work in the absence of VLs but in that case the overall link will assume either a "drop" or "delayed drop" or "no drop" behavior.

[0062] Preferred implementations support a negotiation mechanism, for example one such as is specified by IEEE 802.1x, which is hereby incorporated by reference. The negotiation mechanism can, e.g., determine whether a host device supports LLE and, if so, allow the host to receive VL and credit information, e.g., how many VLs are supported, does a VL uses credit or pause, if credits how many credits, which is the behavior of each individual VL.

[0063] Active buffer management allows for both high reliability and low latency while using small frame buffers. Preferably, the rules for active buffer management are applied differently for drop and no drop VLs.

[0064] Some implementations of the invention support an efficient RDMA protocol that is particularly useful for clustering implementations. In some implementations of the invention, network interface cards ("NICs") implement RDMA for clustering applications and also implement a reliable transport for RDMA. Some aspects of the invention are implemented via user APIs from the User Direct Access Programming Library ("uDAPL"). The uDAPL defines a set of user APIs for all RDMA-capable transports and is hereby incorporated by reference.

[0065] **FIG. 2** is a simplified network diagram that illustrates one example of an LLE solution for simplifying the connectivity of data center **200**. Data center **200** includes LLE switch **240**, having router **260** for connectivity with TCP/IP network **205** and host devices **280** and **285** via firewall **215**. The architecture of exemplary LLE switches is set forth in detail herein. Preferably, the LLE switches of the present invention can run 10 Gb/s Ethernet and have relatively small frame buffers. Some preferred LLE switches support only layer **2** functionality.

[0066] Although LLE switches of the present invention can be implemented using fiber optics and optical transceivers, some preferred LLE switches are implemented using copper connectivity to reduce costs. Some such implementations are implemented according to the proposed IEEE 802.3ak standard called 10Base-CX4, which is hereby incorporated by reference for all purposes. The inventors expect that other implementations will use the emerging standard IEEE P802.3an (10GBASE-T), which is also incorporated by reference for all purposes.

[0067] Servers **210** are also connected with LLE switch **245**, which includes FC gateway **270** for communication

with disk arrays **250**. FC gateway **270** implements FC over Ethernet, which will be described in detail herein, thereby eliminating the need for separate FC and Ethernet networks within data center **200**. Gateway **270** could be a device such as Cisco Systems' MDS 9000 IP Storage Service Module that has been configured with software for performing some methods of the present invention. Ethernet traffic is carried within data center **200** as native format. This is possible because LLE is an extension to Ethernet that can carry FC over Ethernet and RDMA in addition to native Ethernet.

[**0068**] **FIG. 3** illustrates two switches **305** and **310** connected by a physical link **315**. The behavior of switches **305** and **310** is generally governed by IEEE 802.1 and the behavior of physical link **315** is generally governed by IEEE 802.3. In general, the present invention provides for two general behaviors of LLE switches, plus a range of intermediate behaviors. The first general behavior is "drop" behavior, which is similar to that of an Ethernet. The general behavior is "no drop" behavior, which is similar to that of FC. Intermediate behaviors between "drop" and "no drop" behaviors, including but not limited to the "delayed drop" behavior described elsewhere herein, are also provided by the present invention.

[**0069**] In order to implement both behaviors on the same physical link **315**, the present invention provides methods and devices for implementing VLs. VLs are a way to carve out a physical link into multiple logical entities such that traffic in one of the VLs is unaffected by the traffic on other VLs. This is done by maintaining separate buffers (or separate portions of a physical buffer) for each VL. For example, it is possible to use one VL to transmit control plane traffic and some other high priority traffic without being blocked because of low priority bulk traffic on another VL. VLANs may be grouped into different VLs such that traffic in one set of VLANs can proceed unimpeded by traffic on other VLANs.

[**0070**] In the example illustrated by **FIG. 3**, switches **305** and **310** are effectively providing 4 VLs across physical link **315**. Here, VLs **320** and **325** are drop VLs and VLs **330** and **335** are no drop VLs. In order to simultaneously implement both "drop" behavior and "no drop" behavior, there must be at least one VL assigned for each type of behavior, for a total of 2. (It is theoretically possible to have only one VL that is temporarily assigned to each type of behavior, but such an implementation is not desirable.) To support legacy devices and/or other devices lacking LLE functionality, preferred implementations of the invention support a link with no VL and map all the traffic of that link into a single VL at the first LLE port. From a network management perspective, it is preferable to have between 2 and 16 VLs, though more could be implemented.

[**0071**] It is preferable to dynamically partition the link into VLs, because static partitioning is less flexible. In some preferred implementations of the invention, dynamic partitioning is accomplished on a packet-by-packet basis (or a frame-by-frame basis), e.g., by adding an extension header. The present invention encompasses a wide variety of formats for such a header. In some implementations of the invention, there are two types of frames sent on a DCE link: these types are data frames and link management frames.

[**0072**] Although **FIGS. 4 and 5** illustrate formats for an Ethernet data frame and a link management frame, respectively, for implementing some aspects of the invention, alternative implementations of the invention provide frames with more or fewer fields, in a different sequence and other variations. Fields **405** and **410** of **FIG. 4** are standard Ethernet fields for the frame's destination address and source address, respectively. Similarly, protocol type field **430**, payload **435** and CRC field **440** may be those of a standard Ethernet frame.

[**0073**] However, protocol type field **420** indicates that the following fields are those of DCE header **425**. If present, the DCE header will preferably be as close as possible to the beginning of the frame, as it enables easy parsing in hardware. The DCE header may be carried in Ethernet data frames, as shown in **FIG. 4**, as well as in link management frames (see **FIG. 5** and the corresponding discussion). This header is preferably stripped by the MAC and does not need to be stored in a frame buffer. In some implementations of the invention, a continuous flow of link management frames is generated when there is no data traffic present or if regular frames cannot be sent due to lack of credits.

[**0074**] Most information carried in the DCE header is related to the Ethernet frame in which the DCE header is contained. However, some fields are buffer credit fields that are used to replenish credit for the traffic in the opposite direction. In this example, buffer credit fields are only carried by frames having a long DCE header. The credit fields may not be required if the solution uses the Pause frames instead of credits.

[**0075**] TTL field **445** indicates a time to live, which is a number decremented each time frame **400** is forwarded. Normally, a Layer 2 network does not require a TTL field. Ethernet uses a spanning tree topology, which is very conservative. A spanning tree puts constraints on the active topology and allows only one path for a packet from one switch to another.

[**0076**] In preferred implementations of the invention, this limitation on the active topology is not followed. Instead, it is preferred that multiple paths are active at the same time, e.g. via a link state protocol such as OSPF (Open Shortest Path First) or IS-IS (Intermediate System to Intermediate System). However, link state protocols are known to cause transient loops during topology reconfiguration. Using a TTL or similar feature ensures that transient loops do not become a major problem. Therefore, in preferred implementations of the invention, a TTL is encoded in the frame in order to effectively implement a link state protocol at layer 2. Instead of using a link state protocol, some implementations of the invention use multiple spanning trees rooted in the different LLE switches and obtain a similar behavior.

[**0077**] Field **450** identifies the VL of frame **400**. Identification of the VL according to field **450** allows devices to assign a frame to the proper VL and to apply different rules for different VLs. As described in detail elsewhere herein, the rules will differ according to various criteria, e.g., whether a VL is a drop or a no drop VL, whether the VL has a guaranteed bandwidth, whether there is currently congestion on the VL and other factors.

[**0078**] ECN (explicit congestion notification) field **455** is used to indicate that a buffer (or a portion of a buffer allocated to this VL) is being filled and that the source should slow down its transmission rate for the indicated VL.

In preferred implementations of the invention, at least some host devices of the network can understand the ECN information and will apply a shaper, a/k/a a rate limiter, for the VL indicated. Explicit congestion notification can occur in at least two general ways. In one method, a packet is sent for the express purpose of sending an ECN. In another method, the notification is "piggy-backed" on a packet that would have otherwise been transmitted.

[0079] As noted elsewhere, the ECN could be sent to the source or to an edge device. The ECN may originate in various devices of the DCE network, including end devices and core devices. As discussed in more detail in the switch architecture section below, congestion notification and responses thereto are important parts of controlling congestion while maintaining small buffer sizes.

[0080] Some implementations of the invention allow the ECN to be sent upstream from the originating device and/or allow the ECN to be sent downstream, then back upstream. For example, the ECN field **455** may include a forward ECN portion ("FECN") and a backward ECN portion ("BECN"). When a switch port experiences congestion, it can set a bit in the FECN portion and forward the frame normally. Upon receiving a frame with the FECN bit set, an end station sets the BECN bit and the frame is sent back to the source. The source receives the frame, detects that the BECN bit has been set and decreases the traffic being injected into the network, at least for the VL indicated.

[0081] Frame credit field **465** is used to indicate the number of credits that should be allocated for frame **400**. There are many possible ways to implement such a system within the scope of the present invention. The simplest solution is to credit for an individual packet or frame. This may not be the best solution from a buffer management perspective: if a buffer is reserved for a single credit and a credit applies to each packet, an entire buffer is reserved for a single packet. Even if the buffer is only the size of an expected full-sized frame, this crediting scheme will often result in a low utilization of each buffer, because many frames will be smaller than the maximum size. For example, if a full-sized frame is 9 KB and all buffers are 9 KB, but the average frame size is 1500 bytes, only about ⅙ of each buffer is normally in use.

[0082] A better solution is to credit according to a frame size. Although one could make a credit for, e.g., a single byte, in practice it is preferable to use larger units, such as 64 B, 128 B, 256B, 512B, 1024B, etc. For example, if a credit is for a unit of 512B, the aforementioned average 1500-byte frame would require 3 credits. If such a frame were transmitted according to one such implementation of the present invention, frame credit field **465** would indicate that the frame requires 3 credits.

[0083] Crediting according to frame size allows for a more efficient use of buffer space. Knowing the size of a packet not only indicates how much buffer space will be needed, but also indicates when a packet may be moved from the buffer. This may be particularly important, for example, if the internal transmission speed of a switch differs from the rate at which data are arriving at a switch port.

[0084] This example provides a longer version and a shorter version of the DCE header. Long header field **460** indicates whether or not the DCE header is a long or a short version. In this implementation, all data frames contain at least a short header that includes TTL, VL, ECN, and Frame Credit information in fields **445**, **450**, **455** and **465**, respectively. A data frame may contain the long header if it needs to carry the credit information associated with each VL along with the information present in the short header. In this example, there are 8 VLs and 8 corresponding fields for indicating buffer credits for each VL. The use of both short and long DCE headers reduces the overhead of carrying credit information in all frames.

[0085] When there is no data frame to be sent, some embodiments of the invention cause a link management frame ("LMF") to be sent to announce credit information. An LMF may also be used to carry buffer credit from a receiver or to carry transmitted frame credit from a Sender. An LMF should be sent uncredited (Frame Credit=0) because it is preferably consumed by the port and not forwarded. An LMF may be sent on a periodic basis and/or in response to predetermined conditions, for example, after every 10 MB of payload has been transmitted by data frames.

[0086] **FIG. 5** illustrates an example of an LMF format according to some implementations of the invention. LMF **500** begins with standard 6 B Ethernet fields **510** and **520** for the frame's destination address and source address, respectively. Protocol type header **530** indicates that DCE header **540** follows, which is a short DCE header in this example (e.g., Long Header field=0). The VL, TTL, ECN and frame credit fields of DCE header **540** are set to zero by the sender and ignored by the receiver. Accordingly, an LMF may be identified by the following characteristics: Protocol_Type= DCE_Header and Long_Header=0 and Frame_Credit=0.

[0087] Field **550** indicates receiver buffer credits for active VLs. In this example, there are 8 active VLs, so buffer credits are indicated for each active VL by fields **551** through **558**. Similarly, field **560** indicates buffer credits for the sending device, so frame credits are indicated for each active VL by fields **561** through **568**.

[0088] LMF **500** does not contain any payload. If necessary, as in this example, LMF **500** is padded by pad field **570** to 64 Bytes in order to create a legal minimum-sized Ethernet frame. LMF **500** terminates with a standard Ethernet CRC field **580**.

[0089] In general, the buffer-to-buffer crediting scheme of the present invention is implemented according to the following two rules: (1) a Sender transmits a frame when it has a number of credits from the Receiver greater or equal to the number of credits required for the frame to be sent; and (2) a Receiver sends credits to the Sender when it can accept additional frames. As noted above, credits can be replenished using either data frames or LMFs. A port is allowed to transmit a frame for a specific VL only if there are at least as many credits as the frame length (excluding the length of the DCE header).

[0090] Similar rules apply if a Pause Frame is used instead of credits. A Sender transmits a frame when it has not been paused by the Receiver. A Receiver sends a PAUSE frame to the Sender when it cannot accept additional frames.

[0091] Following is a simplified example of data transfer and credit replenishment. **FIG. 6A** illustrates data frame **605**, having a short DCE header, which is sent from switch

B to switch A. After packet **605** arrives at switch A, it will be kept in memory space **608** of buffer **610**. Because some amount of the memory of buffer **610** is consumed, there will be a corresponding decrease in the available credits for switch B. Similarly, when data frame **615** (also having a short DCE header) is sent from switch A to switch B, data frame **615** will consume memory space **618** of buffer **620** and there will be a corresponding reduction in the credits available to switch A.

[**0092**] However, after frames **605** and **615** have been forwarded, corresponding memory spaces will be available in the buffers of the sending switches. At some point, e.g., periodically or on demand, the fact that this buffer space is once again available should be communicated to the device at the other end of the link. Data frames having a long DCE header and LMFs are used to replenish credits. If no credits are being replenished, the short DCE header may be used. Although some implementations use the longer DCE header for all transmissions, such implementations are less efficient because, e.g., extra bandwidth is being consumed for packets that contain no information regarding the replenishment of credits.

[**0093**] **FIG. 6B** illustrates one example of a credit signaling method of the present invention. Conventional credit signaling scheme **650** advertises the new credits that the receiver wants to return. For example, at time t**4** the receiver wants to return 5 credits and therefore the value 5 is carried in the frame. At time t**5** the receiver has no credit to return and therefore the value 0 is carried in the frame. If the frame at time t**4** is lost, five credits are lost.

[**0094**] DCE scheme **660** advertises the cumulative credit value. In other words, each advertisement sums the new credit to be returned to the total number of credits previously returned modulo m (with 8 bits, m is 256). For example, at time t**3** the total number of credits returned since link initialization is 3; at time t**4**, since 5 credits need to be returned, 5 is summed to 3 and 8 is sent in the frame. At time t**5** no credits need to be returned and 8 is sent again. If the frame at time t**4** is lost, no credits are lost, because the frame at time t**5** contains the same information.

[**0095**] According to one exemplary implementation of the invention, a receiving DCE switch port maintains the following information (wherein VL indicates that the information is maintained per virtual lane):

[**0096**] BufCrd[VL]—a modulus counter which is incremented by the number of credits which could be sent;

[**0097**] BytesFromLastLongDCE—the number of bytes sent since the last Long DCE header;

[**0098**] BytesFromLastLMF—the number of bytes sent since the last LMF;

[**0099**] MaxIntBetLongDCE—the maximum interval between sending Long DCE header;

[**0100**] MaxIntBetLMF—the maximum interval between sending LMF; and

[**0101**] FrameRx—a modulus counter which is incremented by the FrameCredit field of the received frame.

[**0102**] A sending DCE switch port maintains the following information:

[**0103**] LastBufCrd[VL]—The last estimated value of the BufCrd[VL] variable of the receiver; and

[**0104**] FrameCrd[VL]—a modulus counter which is incremented by the number of credits used to transmit a frame.

[**0105**] When links come up, the network devices on each end of a link will negotiate the presence of a DCE header. If the header is not present, the network devices will, for example, simply enable the link for standard Ethernet. If the header is present, the network devices will enable features of a DCE link according to some aspect of the invention.

[**0106**] **FIG. 6C** is a flow chart that indicates how a DCE link is initialized according to some implementations of the invention. One of skill in the art will appreciate that the steps of method **680** (like other methods described herein) need not be, and in some cases are not, performed in the order indicated. Moreover, some implementations of these methods include more or fewer steps than are indicated.

[**0107**] In step **661**, the physical link comes up between two switch ports and in step **663** a first packet is received. In step **665**, it is determined (by the receiving port) whether the packet has a DCE header. If not, the link is enabled for standard Ethernet traffic. If the packet has a DCE header, the ports perform steps to configure the link as a DCE link. In step **671**, the receiver and sender zero out all arrays relating to traffic on the link. In step **673**, the value of MaxIntBetLongDCE is initialized to a configured value and in step **675**, MaxIntBetLMF is initialized to a configured value.

[**0108**] In step **677**, the two DCE ports exchange available credit information for each VL, preferably by sending an LMF. If a VL is not used, its available credit is announced as 0. In step **679**, the link is enabled for DCE and normal DCE traffic, including data frames, may be sent on the link according to the methods described herein.

[**0109**] To work properly in the presence of a single frame loss, the DCE self-recovering mechanism of preferred implementations requires that the maximum number of credits advertised in a frame be less than ½ of the maximum advertisable value. In some implementations of the short DCE header each credit field is 8 bits, i.e. a value of 256. Thus, up to 127 additional credits can be advertised in a single frame. The maximum value of 127 credits is reasonable, since the worst situation is represented by a long sequence of minimum size frames in one direction and a single jumbo frame in the opposite direction. During the transmission of a 9 KB jumbo frame, the maximum number of minimum size frames is approximately 9220 B/84 B=110 credits (assuming a 9200-byte maximum transmission unit and 20 bytes of IPG and Preamble).

[**0110**] If multiple consecutive frames are lost, an LMF recovery method can "heal" the link. One such LMF recovery method works on the idea that, in some implementations, internal counters maintained by the ports of DCE switches are 16 bits, but to conserve bandwidth, only the lower 8 bits are transmitted in the long DCE header. This works well if there are no consecutive frame losses, as explained before. When the link experiences multiple consecutive errors, the long DCE header may no longer be able to synchronize the

counters, but this is achieved through LMFs that contain the full 16 bits of all the counters. The 8 additional bits allow the recovery of 256 times more errors for a total of 512 consecutive errors. Preferably, before this situation is encountered the link is declared inoperative and reset.

[0111] In order to implement a low latency Ethernet system, at least 3 general types of traffic must be considered. These types are IP network traffic, storage traffic and cluster traffic. As described in detail above, LLE provides "no drop" VLs with FC-like characteristics that are suitable for, e.g., storage traffic. The "no drop" VL will not lose packets/frames and may be provided according to a simple stack, e.g., as shown in **FIG. 8**. Only a small "shim" of FC over LLE **810** is between LLE layer **805** and FC Layer 2 (**815**). Layers **815**, **820** and **825** are the same as those of FC stack **750**. Therefore, storage applications that were previously running over FC can be run over LLE.

[0112] The mapping of FC frames to FC over Ethernet frames according to one exemplary implementation of FC over LLE layer **810** will now be described with reference to **FIGS. 9A, 9B** and **10**. **FIG. 9A** is a simplified version of an FC frame. FC frame **900** includes SOF **905** and EOF **910**, which are ordered sets of symbols used not only to delimit the boundaries of frame **900**, but also to convey information such as the class of the frame, whether the frame is the start or the end of a sequence (a group of FC frames), whether the frame is normal or abnormal, etc. At least some of these symbols are illegal "code violation" symbols. FC frame **900** also includes 24-bit source FC ID field **915**, 24-bit destination FC ID field **920** and payload **925**.

[0113] One goal of the present invention is to convey storage information contained in an FC frames, such as FC frame **900**, across an Ethernet. **FIG. 10** illustrates one implementation of the invention for an LLE that can convey such storage traffic. Network **1000** includes LLE cloud **1005**, to which devices **1010**, **1015** and **1020** are attached. LLE cloud **1005** includes a plurality of LLE switches **1030**, exemplary architecture for which is discussed elsewhere herein. Devices **1010**, **1015** and **1020** may be host devices, servers, switches, etc. Storage gateway **1050** connects LLE cloud **1005** with storage devices **1075**. For the purposes of moving storage traffic, network **1000** may be configured to function as an FC network. Accordingly, the ports of devices **1010**, **1015** and **1020** each have their own FC ID and ports of storage devices **1075** have FC IDs.

[0114] In order to move efficiently the storage traffic, including frame **900**, between devices **1010**, **1015** and **1020** and storage devices **1075**, some preferred implementations of the invention map information from fields of FC frame **900** to corresponding fields of LLE packet **950**. LLE packet **950** includes SOF **955**, organization ID field **965** and device ID field **970** of destination MAC field, organization ID field **975** and device ID field **980** of source MAC field, protocol type field **985**, field **990** and payload **995**.

[0115] Preferably, fields **965**, **970**, **975** and **980** are all 24-bit fields, in conformance with normal Ethernet protocol. Accordingly, in some implementations of the invention, the contents of destination FC ID field **915** of FC frame **900** are mapped to one of fields **965** or **970**, preferably to field **970**. Similarly, the contents of source FC ID field **920** of FC frame **900** are mapped to one of fields **975** or **980**, preferably to field **980**. It is preferable to map the contents of destination FC ID field **915** and source FC ID field **920** of FC frame **900** to fields **970** and **980**, respectively, of LLE packet **950** because, by convention, many device codes are assigned by the IEEE for a single organization code. This mapping function may be performed, for example, by storage gateway **1050**.

[0116] Therefore, the mapping of FC frames to LLE packets may be accomplished in part by purchasing, from the IEEE, an Organization Unique Identifier ("OUI") codes that correspond to a group of device codes. In one such example, the current assignee, Cisco Systems, pays the registration fee for an OUI, assigns the OUI to "FC over Ethernet." A storage gateway configured according to this aspect of the present invention (e.g., storage gateway **1050**) puts the OUI in fields **965** and **975**, copies the 24-bit contents of destination FC ID field **915** to 24-bit field **970** and copies the 24-bit contents of source FC ID field **920** to 24-bit field **980**. The storage gateway inserts a code in protocol type field **985** that indicates FC over Ethernet and copies the contents of payload **925** to payload field **995**.

[0117] Because of the aforementioned mapping, no MAC addresses need to be explicitly assigned on the storage network. Nonetheless, as a result of the mapping, an algorithmically derived version of the destination and source FC IDs are encoded in corresponding portions of the LLE frame that would be assigned, in a normal Ethernet packet, to destination and source MAC addresses. Storage traffic may be routed on the LLE network by using the contents of these fields as if they were MAC address fields.

[0118] The SOF field **905** and EOF field **910** contain ordered sets of symbols, some of which (e.g., those used to indicate the start and end of an FC frame) are reserved symbols that are sometimes referred to as "illegal" or "code violation" symbols. If one of these symbols were copied to a field within LLE packet **950** (for example, to field **990**), the symbol would cause an error, e.g., by indicating that LLE packet **950** should terminate at that symbol. However, the information that is conveyed by these symbols must be retained, because it indicates the class of the FC frame, whether the frame is the start or the end of a sequence and other important information.

[0119] Accordingly, preferred implementations of the invention provide another mapping function that converts illegal symbols to legal symbols. These legal symbols may then be inserted in an interior portion of LLE packet **950**. In one such implementation, the converted symbols are placed in field **990**. Field **990** does not need to be very large; in some implementations, it is only 1 or 2 bytes in length.

[0120] To allow the implementation of cut-through switching field **990** may be split into two separate fields. For example, one field may be at the beginning of the frame and one may be at the other end of the frame.

[0121] The foregoing method is but one example of various techniques for encapsulating an FC frame inside an extended Ethernet frame. Alternative methods include any convenient mapping that involves, for example, the derivation of the tuple {VLAN, DST MAC Addr, Src MAC Addr} from the tuple {VSAN, D_ID, S_ID}.

[0122] The aforementioned mapping and symbol conversion processes produce an LLE packet, such as LLE packet **950**, that allows storage traffic to and from FC-based storage

devices **1075** to be forwarded across LLE cloud **1005** to end node devices **1010**, **1015** and **1020**. The mapping and symbol conversion processes can be run, e.g., by storage gateway **1050**, on a frame-by-frame basis.

[**0123**] Accordingly, the present invention provides exemplary methods for encapsulating an FC frame inside an extended Ethernet frame at the ingress edge of an FC-Ethernet cloud. Analogous method of the invention provide for an inverse process that is performed at the egress edge of the Ethernet-FC cloud. An FC frame may be decapsulated from an extended Ethernet frame and then transmitted on an FC network.

[**0124**] Some such methods include these steps: receiving an Ethernet frame (encapsulated, for example, as described herein); mapping destination contents of a first portion of a destination MAC field of the Ethernet frame to a destination FC ID field of an FC frame; mapping source contents of a second portion of a source MAC field of the Ethernet frame of a source FC ID field of the FC frame; converting legal symbols of the Ethernet frame to illegal symbols; inserting the illegal symbols into selected fields of the FC frame; mapping payload contents of a payload field of the Ethernet frame to an FC frame payload field; and transmitting the FC frame on the FC network.

[**0125**] No state information about the frames needs to be retained. Accordingly, the frames can be processed quickly, for example at a rate of 40 Gb/s. The end nodes can run storage applications based on SCSI, because the storage applications see the SCSI layer **825** of LLE stack **800**, depicted in **FIG. 8**. Instead of forwarding storage traffic across switches dedicated to FC traffic, such as FC switches **140** and **145** shown in **FIG. 1**, such FC switches can be replaced by LLE switches **1030**.

[**0126**] Moreover, the functionality of LLE switches allows for an unprecedented level of management flexibility. Referring to **FIG. 11**, in one management scheme, each of the LLE switches **1130** of LLE cloud **1105** may be treated as separate FC switches. Alternatively, some or all of the LLE switches **1130** may be aggregated and treated, for management purposes, as FC switches. For example, virtual FC switch **1140** has been formed, for network management purposes, by treating all LLE switches in LLE cloud **1105** as a single FC switch. All of the ports of the individual LLE switches **1130**, for example, would be treated as ports of virtual FC switch **1140**. Alternatively, smaller numbers of LLE switches **1130** could be aggregated. For example, 3 LLE switches have been aggregated to form virtual FC switch **1160** and 4 LLE switches have been aggregated to form virtual FC switch **1165**. A network manager may decide how many switches to aggregate by considering, inter alia, how many ports the individual LLE switches have. The control plane functions of FC, such as zoning, DNS, FSPF and other functions may be implemented by treating each LLE switch as an FC switch or by aggregating multiple LLE switches as one virtual FC switch.

[**0127**] Also, the same LLE cloud **1105** may support numerous virtual networks. Virtual local area networks ("VLANs") are known in the art for providing virtual Ethernet-based networks. U.S. Pat. No. 5,742,604, entitled "Interswitch Link Mechanism for Connecting High-Performance Network Switches" describes relevant systems and is hereby incorporated by reference. Various patent applications of the present assignee, including U.S. patent application Ser. No. 10/034,160, entitled "Methods And Apparatus For Encapsulating A Frame For Transmission In A Storage Area Network" and filed on Dec. 26, 2001, provide methods and devices for implementing virtual storage area networks ("VSANs") for FC-based networks. This application is hereby incorporated by reference in its entirety. Because LLE networks can support both Ethernet traffic and FC traffic, some implementations of the invention provide for the formation of virtual networks on the same physical LLE cloud for both FC and Ethernet traffic.

[**0128**] **FIG. 12** is a schematic diagram that illustrates a simplified architecture of DCE switch **1200** according to one embodiment of the invention. DCE switch **1200** includes N line cards, each of which characterized by and ingress side (or input) **1205** and an egress side (or output) **1225**. Line card ingress sides **1205** are connected via switching fabric **1250**, which includes a crossbar in this example, to line card egress sides **1225**.

[**0129**] In this implementation, buffering is performed on both the input and output sides. Other architectures are possible, e.g., those having input buffers, output buffers and shared memory. Accordingly, each of input line cards **1205** includes at least one buffer **1210** and each of output line cards **1225** includes at least one buffer **1230**, which may be any convenient type of buffer known in the art, e.g., an external DRAM-based buffer or an on-chip SRAM-based buffer. The buffers **1210** are used for input buffering, e.g., to temporarily retain packets while awaiting sufficient buffer to become available at the output linecard to store the packets to be sent across switching fabric **1250**. Buffers **1230** are used for output buffering, e.g., to temporarily retain packets received from one or more of the input line cards **1205** while awaiting sufficient credits for the packets to be transmitted to another DCE switch.

[**0130**] It is worthwhile noting that while credits may be used internally to a switch and also externally, there is not necessarily a one-to-one mapping between internal and external credits. Moreover, it is possible to use PAUSE frame either internally or externally. For example, any of the four possible combinations PAUSE-PAUSE, PAUSE-CREDITS, CREDITs-PAUSE and CREDIT-CREDIT may produce viable solutions.

[**0131**] DCE switch **1200** includes some form of credit mechanism for exerting flow control. This flow control mechanism can exert back pressure on buffers **1210** when an output queue of one of buffers **1230** has reached its maximum capacity. For example, prior to sending a frame, one of the input line cards **1205** may request a credit from arbiter **1240** (which may be, e.g., a separate chip located at a central location or a set of chips distributed across the output linecards) prior to sending a frame from input queue **1215** to output queue **1235**. Preferably, the request indicates the size of the frame, e.g., according to the frame credit field of the DCE header. Arbiter **1240** will determine whether output queue **1235** can accept the frame (i.e., output buffer **1230** has enough space to accommodate the frame). If so, the credit request will be granted and arbiter **1240** will send a credit grant to input queue **1215**. However, if output queue **1235** is too full, the request will be denied and no credits will be sent to input queue **1215**.

[**0132**] DCE switch **1200** needs to be able to support both the "drop" and "no drop" behavior required for virtual lanes,

as discussed elsewhere herein. The "no drop" functionality is enabled, in part, by applying internally to the DCE switch some type of credit mechanism like the one described above. Externally, the "no drop" functionality can be implemented in accordance with the buffer-to-buffer credit mechanism described earlier or PAUSE frames. For example, if one of input line cards **1205** is experiencing back pressure from one or more output line cards **1225** through the internal credit mechanism, the line card can propagate that back pressure externally in an upstream direction via a buffer-to-buffer credit system like that of FC.

[**0133**] Preferably, the same chip (e.g., the same ASIC) that is providing "no drop" functionality will also provide "drop" functionality like that of a classical Ethernet switch. Although these tasks could be apportioned between different chips, providing both drop and no drop functionality on the same chip allows DCE switches to be provided at a substantially lower price.

[**0134**] Each DCE packet will contain information, e.g., in the DCE header as described elsewhere herein, indicating the virtual lane to which the DCE packet belongs. DCE switch **1200** will handle each DCE packet according to whether the VL to which the DCE packet is assigned is a drop or a no drop VL.

[**0135**] **FIG. 13** illustrates an example of partitioning a buffer for VLs. In this example, 4 VLs are assigned. VL **1305** and VL **1310** are drop VLs. VL **1315** and VL **1320** are no drop VLs. In this example, input buffer **1300** has specific areas assigned for each VL: VL **1305** is assigned to buffer space **1325**, VL **1310** is assigned to buffer space **1330**, VL **1315** is assigned to buffer space **1335** and VL **1320** is assigned to buffer space **1340**. Traffic on VL **1305** and VL **1310** is managed much like normal Ethernet traffic, in part according to the operations of buffer spaces **1325** and **1330**. Similarly, the no drop feature of VLs **1315** and **1320** is implemented, in part, according to a buffer-to-buffer credit flow control scheme that is enabled only for buffer spaces **1335** and **1340**.

[**0136**] In some implementations, the amount of buffer space assigned to a VL can be dynamically assigned according to criteria such as, e.g., buffer occupancy, time of day, traffic loads/congestion, guaranteed minimum bandwidth allocation, known tasks requiring greater bandwidth, maximum bandwidth allocation, etc. Preferably, principles of fairness will apply to prevent one VL from obtaining an inordinate amount of buffer space.

[**0137**] Within each buffer space there is an organization of data in data structures which are logical queues (virtual output queues or VOQs") associated with destinations. ("A Practical Scheduling Algorithm to Achieve 100% Throughput in Input-Queued Switches," by Adisak Mekkittikul and Nick McKeown, Computer Systems Laboratory, Stanford University (InfoCom 1998) and the references cited therein describe relevant methods for implementing VOQs and are hereby incorporated by reference.) The destinations are preferably destination port/virtual lane pairs. Using a VOQ scheme avoids head of line blocking at the input linecard caused when an output port is blocked and/or when another virtual lane of the destination output port is blocked.

[**0138**] In some implementations, VOQs are not shared between VLs. In other implementations, a VOQ can be shared between drop VLs or no-drop VLs. However, a VOQ should not be shared between no drop VLs and drop VLS.

[**0139**] The buffers of DCE switches can implement various types of active queue management. Some preferred embodiments of DCE switch buffers provide at least 4 basic types of active queue management: flow control; dropping for drop VLs or marking for no-drop VLs for congestion avoidance purposes; dropping to avoid deadlocks in no drop VLs; and dropping for latency control.

[**0140**] Preferably, flow control for a DCE network has at least two basic manifestations. One flow control manifestation is a buffer-to-buffer, credit-based flow control that is used primarily to implement the "no drop" VLs. Another flow control manifestation of some preferred implementations involves an explicit upstream congestion notification. This explicit upstream congestion notification may be implemented, for example, by the explicit congestion notification ("ECN") field of the DCE header, as described elsewhere herein.

[**0141**] **FIG. 14** illustrates DCE network **1405**, including edge DCE switches **1410**, **1415**, **1425** and **1430** and core DCE switch **1420**. In this instance, buffer **1450** of core DCE switch **1420** is implementing 3 types of flow control. One is buffer-to-buffer flow control indication **1451**, which is communicated by the granting (or not) of buffer-to-buffer credits between buffer **1450** and buffer **1460** of edge DCE switch **1410**.

[**0142**] Buffer **1450** is also transmitting 2 ECNs **1451** and **1452**, both of which are accomplished via the ECN field of the DCE headers of DCE packets. ECN **1451** would be considered a core-to-edge notification, because it is sent by core device **1420** and received by buffer **1460** of edge DCE switch **1410**. ECN **1452** would be considered a core-to-end notification, because it is sent by core device **1420** and received by NIC card **1465** of end-node **1440**.

[**0143**] In some implementations of the invention, ECNs are generated by sampling a packet that is stored into a buffer subject to congestion. The ECN is sent to the source of that packet by setting its destination address equal to the source address of the sampled packet. The edge device will know whether the source supports DCE ECN, as end-node **1440** does, or it doesn't, as in the case of end-node **1435**. In the latter case, edge device **1410** will terminate the ECN and implement the appropriate action.

[**0144**] Active queue management (AQM) will be performed in response to various criteria, including but not limited to buffer occupancy (e.g., per VL), queue length per VOQ and the age of a packet in a VOQ. For the sake of simplicity, in this discussion of AQM it will generally be assumed that a VOQ is not shared between VLs.

[**0145**] Some examples of AQM according to the present invention will now be described with reference to **FIG. 15**. **FIG. 15** depicts buffer usage at a particular time. At that time, portion **1505** of physical buffer **1500** has been allocated to a drop VL and portion **1510** has been allocated to a no drop VL. As noted elsewhere herein, the amount of buffer **1500** that is allocated to drop VLs or no drop VLs can change over time. Of the portion **1505** allocated to a drop VL, part **1520** is currently in use and part **1515** is not currently in use.

[0146] Within portions **1505** and **1510**, there numerous VOQs, including VOQs **1525**, **1530** and **1535**. In this example, a threshold VOQ length L has been established. VOQs **1525** and **1535** have a length greater than L and, VOQ **1530** has a length less than L. A long VOQ indicates downstream congestion. Active queue management preferably prevents any VOQ from becoming too large, because otherwise downstream congestion affecting one VOQ will adversely affect traffic for other destinations.

[0147] The age of a packet in a VOQ is another criterion used for AQM. In preferred implementations, a packet is time stamped when it comes into a buffer and queued into the proper VOQ. Accordingly, packet **1540** receives time stamp **1545** upon its arrival in buffer **1500** and is placed in a VOQ according to its destination and VL designation. As noted elsewhere, the VL designation will indicate whether to apply drop or no drop behavior. In this example, the header of packet **1540** indicates that packet **1540** is being transmitted on a drop VL and has a destination corresponding to that of VOQ **1525**, so packet **1540** is placed in VOQ **1525**.

[0148] By comparing the time of time stamp **1545** with a current time, the age of packet **1540** may be determined at subsequent times. In this context, "age" refers only to the time that the packet has spent in the switch, not the time in some other part of the network. Nonetheless, conditions of other parts of the network may be inferred by the age of a packet. For example, if the age of a packet becomes relatively large, this condition indicates that the path towards the destination of the packet is subject to congestion.

[0149] In preferred implementations, a packet having an age that exceeds a predetermined age will be dropped. Multiple drops are possible, if at the time of age determination it is found that a number of packets in a VOQ exceed a predetermined age threshold.

[0150] In some preferred implementations, there are separate age limits for latency control (T_L) and for avoiding deadlocks (T_D). The actions to be taken when a packet reaches T_L preferably depend on whether the packet is being transmitted on a drop or a no drop VL. For traffic on a no drop lane, data integrity is more important than latency. Therefore, in some implementations of the invention, when the age of a packet in a no drop VL exceeds T_L, the packet is not dropped but another action may be taken. For example, in some such implementations, the packet may be marked and/or an upstream congestion notification may be triggered. For packets in a drop VL, latency control is relatively more important and therefore more aggressive action is appropriate when the age of a packet exceeds T_L. For example, a probabilistic drop function may be applied to the packet.

[0151] Graph **1600** of **FIG. 16** provides some examples of probabilistic drop functions. According to drop functions **1605**, **1610** and **1615**, when the age of a packet exceeds T_{CO}, i.e., the latency cut-off threshold, the probability that the packet will intentionally be dropped increases from 0% to 100% as its age increases up to T_L, depending on the function. Drop function **1620** is a step function, having a 0% probability of intentional dropping until T_L is reached. All of drop functions **1605**, **1610**, **1615** and **1620** reach a 100% chance of intentional drop when the age of the packet reaches T_L. Although T_{CO}, T_L, and T_D may be any convenient times, in some implementations of the invention T_{CO} is in the order of tens of microseconds, T_L is on the order of ones to tens of milliseconds and T_D is on the order of hundreds of milliseconds, e.g., 500 milliseconds.

[0152] If the age of the packet in a drop or a no drop VL exceeds T_D, the packet will be dropped. In preferred implementations, T_D is larger for no drop VLs than for drop VLs. In some implementations, T_L and/or T_D may also depend, in part, on the bandwidth of the VL on which the packet is being transmitted and on the number of VOQs simultaneously transmitting packets to that VL.

[0153] For no drop VL, a probability function similar to those shown in **FIG. 16** may be used to trigger an upstream congestion notification or to set the Congestion Experienced bit (CE) in the header of TCP packets belonging to connections capable to support TCP ECN.

[0154] In some implementations, whether a packet is dropped, an upstream congestion notification is sent, or the CE bit of a TCP packet is marked depends not only on the age of a packet but also on the length of the VOQ in which the packet is placed. If such length is above a threshold L_{max}, the AQM action is taken; otherwise it will be performed on first packet dequeued from a VOQ whose length exceeds the L_{max} threshold.

[0155] Use of Buffer Occupancy Per VL

[0156] As shown in **FIG. 15**, a buffer is apportioned to VLs. For parts of the buffer apportioned to drop VLs (such as portion **1505** of buffer **1500**), a packet will be dropped if the occupancy of a VL, at any given time, is greater than a predetermined maximum value. In some implementations, an average occupancy of a VL is computed and maintained. An AQM action may be taken based on such average occupancy. For example, being portion **1505** associated with a no-drop VL, DCE ECNs will be triggered instead of packet drops as in the case of portion **1510**, which is associated with a drop VL.

[0157] **FIG. 17** depicts graph **1700** of VL occupancy B(VL) (the vertical axis) over time (the horizontal axis). Here, B_T is a threshold value of B(VL). In some implementations of the invention, some packets in a VL will be dropped at times during which it is determined that B(VL) has reached. The actual value of B(VL) over time is shown by curve **1750**, but B(VL) is only determined at times t_1 through t_N. In this example, packets would be dropped at points **1705**, **1710** and **1715**, which correspond to times t_2, t_3 and t_6. The packets may be dropped according to their age (e.g., oldest first), their size, the QoS for the virtual network of the packets, randomly, according to a drop function, or otherwise.

[0158] In addition (or alternatively), an active queue management action may be taken when an average value of B(VL), a weighted average value, etc., reaches or exceeds B_T. Such averages may be computed according to various methods, e.g., by summing the determined values of B(VL) and dividing by the number of determinations. Some implementations apply a weighting function, e.g., by according more weight to more recent samples. Any type of weighting function known in the art may be applied.

[0159] The active queue management action taken may be, for example, sending an ECN and/or applying a probabilistic drop function, e.g., similar to one of those illustrated

in **FIG. 18**. In this example, the horizontal axis of graph **1880** is the average value of B(VL). When the average value is below a first value **1805**, there is a 0% chance of intentionally dropping the packet. When the average value reaches or exceeds a second value **1810**, there is a 100% chance of intentionally dropping the packet. Any convenient function may be applied to the intervening values, whether a function similar to **1815**, **1820** or **1825** or another function.

[**0160**] Returning to **FIG. 15**, it is apparent that the length of VOQs **1525** and **1535** exceed a predetermined length L. In some implementations of the invention, this condition triggers an active queue management response, e.g., the sending of one or more ECNs. Preferably, packets contained in buffer **1500** will indicate whether the source is capable of responding to an ECN. If the sender of a packet cannot respond to an ECN, this condition may trigger a probabilistic drop function or simply a drop. VOQ **1535** is not only longer than predetermined length L_1, it is also longer than predetermined length L_2. According to some implementations of the invention, this condition triggers the dropping of a packet. Some implementations of the invention use average VOQ lengths as criteria for triggering active queue management responses, but this is not preferred due to the large amount of computation required.

[**0161**] It is desirable to have multiple criteria for triggering AQM actions. For example, while it is very useful to provide responses to VOQ length, such measures would not be sufficient for DCE switches having approximately 1 to 2 MB of buffer space per port. For a given buffer, there may be thousands of active VOQs. However, there may only be enough storage space for on the order of 10^3 packets, possibly fewer. Therefore, it may be the case that no individual VOQ has enough packets to trigger any AQM response, but that a VL is running out of space.

[**0162**] Queue Management for No Drop VLs

[**0163**] In preferred implementations of the invention, the main difference between active queue management of drop and no drop VLs is that the same criterion (or criteria) that would trigger a packet drop for a drop VL will result in an DCE ECN being transmitted or a TCP CE bit being marked for no drop VL. For example, a condition that would trigger a probabilistic packet drop for a drop VL would generally result in a probabilistic ECN to an upstream edge device or an end (host) device. Credit-based schemes are not based on where a packet is going, but instead are based on where packets are coming from. Therefore, upstream congestion notifications help to provide fairness of buffer use and to avoid deadlock that might otherwise arise if the sole method of flow control for no drop VLs were a credit-based flow control.

[**0164**] For example, with regard to the use of buffer occupancy per VL as a criterion, packets are preferably not dropped merely because the buffer occupancy per VL has reached or exceeded a threshold value. Instead, for example, a packet would be marked or an ECN would be sent. Similarly, one might still compute some type of average buffer occupancy per VL and apply a probabilistic function, but the underlying action to be taken would be marking and/or sending an ECN. The packet would not be dropped.

[**0165**] However, even for a no drop VL, packets will still be dropped in response to blocking or deadlock conditions, e.g., as indicated by the age of a packet exceeding a threshold as described elsewhere herein. Some implementations of the invention also allow for packets of a no drop VL to be dropped in response to latency conditions. This would depend on the degree of importance placed on latency for that particular no drop VL. Some such implementations apply a probabilistic dropping algorithm. For example, some cluster applications may place a higher value on latency considerations as compared to a storage application. Data integrity is still important to cluster applications, but it may be advantageous to reduce latency by foregoing some degree of data integrity. In some implementations, larger values T_L (i.e., the latency control threshold) may be used for no drop lanes than the corresponding values used for drop lanes.

[**0166**] **FIG. 19** illustrates an example of a network device that may be configured to implement some methods of the present invention. Network device **1960** includes a master central processing unit (CPU) **1962**, interfaces **1968**, and a bus **1967** (e.g., a PCI bus). Generally, interfaces **1968** include ports **1969** appropriate for communication with the appropriate media. In some embodiments, one or more of interfaces **1968** includes at least one independent processor **1974** and, in some instances, volatile RAM. Independent processors **1974** may be, for example ASICs or any other appropriate processors. According to some such embodiments, these independent processors **1974** perform at least some of the functions of the logic described herein. In some embodiments, one or more of interfaces **1968** control such communications-intensive tasks as media control and management. By providing separate processors for the communications-intensive tasks, interfaces **1968** allow the master microprocessor **1962** efficiently to perform other functions such as routing computations, network diagnostics, security functions, etc.

[**0167**] The interfaces **1968** are typically provided as interface cards (sometimes referred to as "line cards"). Generally, interfaces **1968** control the sending and receiving of data packets over the network and sometimes support other peripherals used with the network device **1960**. Among the interfaces that may be provided are Fibre Channel ("FC") interfaces, Ethernet interfaces, frame relay interfaces, cable interfaces, DSL interfaces, token ring interfaces, and the like. In addition, various very high-speed interfaces may be provided, such as fast Ethernet interfaces, Gigabit Ethernet interfaces, ATM interfaces, HSSI interfaces, POS interfaces, FDDI interfaces, ASI interfaces, DHEI interfaces and the like.

[**0168**] When acting under the control of appropriate software or firmware, in some implementations of the invention CPU **1962** may be responsible for implementing specific functions associated with the functions of a desired network device. According to some embodiments, CPU **1962** accomplishes all these functions under the control of software including an operating system (e.g. Linux, VxWorks, etc.), and any appropriate applications software.

[**0169**] CPU **1962** may include one or more processors **1963** such as a processor from the Motorola family of microprocessors or the MIPS family of microprocessors. In an alternative embodiment, processor **1963** is specially designed hardware for controlling the operations of network device **1960**. In a specific embodiment, a memory **1961** (such as non-volatile RAM and/or ROM) also forms part of

CPU **1962**. However, there are many different ways in which memory could be coupled to the system. Memory block **1961** may be used for a variety of purposes such as, for example, caching and/or storing data, programming instructions, etc.

[**0170**] Regardless of network device's configuration, it may employ one or more memories or memory modules (such as, for example, memory block **1965**) configured to store data, program instructions for the general-purpose network operations and/or other information relating to the functionality of the techniques described herein. The program instructions may control the operation of an operating system and/or one or more applications, for example.

[**0171**] Because such information and program instructions may be employed to implement the systems/methods described herein, the present invention relates to machine-readable media that include program instructions, state information, etc. for performing various operations described herein. Examples of machine-readable media include, but are not limited to, magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD-ROM disks; magneto-optical media; and hardware devices that are specially configured to store and perform program instructions, such as read-only memory devices (ROM) and random access memory (RAM). The invention may also be embodied in a carrier wave traveling over an appropriate medium such as airwaves, optical lines, electric lines, etc. Examples of program instructions include both machine code, such as produced by a compiler, and files containing higher level code that may be executed by the computer using an interpreter.

[**0172**] Although the system shown in **FIG. 19** illustrates one specific network device of the present invention, it is by no means the only network device architecture on which the present invention can be implemented. For example, an architecture having a single processor that handles communications as well as routing computations, etc. is often used. Further, other types of interfaces and media could also be used with the network device. The communication path between interfaces/line cards may be bus based (as shown in **FIG. 19**) or switch fabric based (such as a cross-bar).

[**0173**] While the invention has been particularly shown and described with reference to specific embodiments thereof, it will be understood by those skilled in the art that changes in the form and details of the disclosed embodiments may be made without departing from the spirit or scope of the invention. For example, some implementations of the invention allow a VL to change from being a drop VL to a no drop VL. Thus, the examples described herein are not intended to be limiting of the present invention. It is therefore intended that the appended claims will be interpreted to include all variations, equivalents, changes and modifications that fall within the true spirit and scope of the present invention.

We claim:

1. A method for carrying more than one type of traffic on a single physical link, the method comprising:

logically partitioning traffic on a physical link into a plurality of virtual lanes;

applying a first set of rules to first traffic on a first virtual lane; and

applying a second set of rules to second traffic on a second virtual lane.

2. The method of claim 1, further comprising the step of differentiating service per virtual lane.

3. The method of claim 1, further comprising the steps of applying third through sets of rules to traffic on third through N^{th} virtual lanes.

4. The method of claim 1, wherein the first traffic comprises Ethernet traffic.

5. The method of claim 1, wherein the second traffic comprises storage traffic.

6. The method of claim 1, wherein the second traffic comprises Inter Process Communication traffic.

7. The method of claim 1, wherein the first set of rules causes frames to be dropped in response to latency.

8. The method of claim 1, wherein the second set of rules does not cause frames to be dropped in response to latency.

9. The method of claim 1, wherein the first set of rules causes an explicit congestion notification to be transmitted in response to latency.

10. The method of claim 1, wherein the second set of rules causes an explicit congestion notification to be transmitted in response to latency.

11. The method of claim 1, wherein the second set of rules causes frames to be dropped to avoid deadlocks.

12. The method of claim 1, wherein the first set of rules applies a probabilistic drop function in response to latency.

13. The method of claim 1, further comprising the step of implementing flow control per virtual lane by using one or more of a buffer-to-buffer crediting scheme and PAUSE frames.

14. The method of claim 2, wherein service is differentiated according to one or more of quality of service and access control.

15. The method of claim 9, wherein the explicit congestion notification is sent to one of a source device or an edge device.

16. The method of claim 9, wherein the explicit congestion notification is sent via one of a data frame or a control frame.

17. The method of claim 13, wherein the buffer-to-buffer crediting scheme comprises crediting according to one of frame size and a number of frames.

18. The method of claim 13, wherein buffer-to-buffer credits are indicated via one of a data frame or a control frame.

19. A network device, comprising:

means for logically partitioning traffic on a physical link into a plurality of virtual lanes;

means for applying a first set of rules to first traffic on a first virtual lane; and

means for applying a second set of rules to second traffic on a second virtual lane.

20. The network device of claim 19, wherein the first traffic comprises Ethernet traffic.

21. The network device of claim 19, wherein the second traffic comprises storage traffic.

22. The network device of claim 19, further comprising means for differentiating service per virtual lane.

23. The network device of claim 19, further comprising means for implementing flow control per virtual lane, the flow control comprising one or more of a buffer-to-buffer crediting scheme and the use of PAUSE frames.

24. The network device of claim 19, wherein the second traffic comprises Inter Process Communication traffic.

25. The network device of claim 23, wherein the buffer-to-buffer crediting scheme comprises crediting according to one of frame size and a number of frames.

26. The network device of claim 23, wherein buffer-to-buffer credits are indicated via one of a data frame or a control frame.

27. A method of transporting a plurality of traffic types on a single virtual link, the method comprising:

receiving a first frame on a physical link;

inspecting one or more fields of the first frame;

determining, based on the one or more fields, that first virtual lane rules should apply to the first frame; and

applying the first virtual lane rules to the first frame.

28. The method of claim 27, further comprising:

receiving a second frame on a physical link;

inspecting one or more fields of the second frame;

determining, based on the one or more fields, that second virtual lane rules should apply to the second frame; and

applying the second virtual lane rules to the second frame.

29. The method of claim 27, wherein the determining step comprises parsing explicit virtual lane identification information.

30. The method of claim 27, wherein the determining step comprises:

parsing implicit virtual lane identification information; and

mapping the implicit virtual lane identification information with a corresponding virtual lane.

31. The method of claim 27, wherein the first virtual lane rules comprise a first set of active buffer management rules and wherein the second virtual lane rules comprise a second set of active buffer management rules.

32. The method of claim 27, wherein the first virtual lane rules and the second virtual lane rules differentiate service per virtual lane.

33. A method of transporting a plurality of traffic types on a single virtual link, the method comprising:

initializing a physical link between a first switch port and a second switch port; and

determining whether the frame contains information required for establishing virtual lanes on the physical link.

34. The method of claim 33, further comprising the step of logically partitioning traffic on the physical link into a plurality of virtual lanes when it is determined that the frame contains information required for establishing virtual lanes on the physical link.

35. The method of claim 33, further comprising the step of establishing a standard Ethernet connection on the physical link when it is determined that the frame does not contain information required for establishing virtual lanes on the physical link.

36. An apparatus for transporting a plurality of traffic types on a single virtual link, the apparatus comprising:

means for initializing a physical link between a first switch port and a second switch port; and

means for determining whether the frame contains information required for establishing virtual lanes on the physical link.

37. The apparatus of claim 36, further comprising means for logically partitioning traffic on the physical link into a plurality of virtual lanes when it is determined that the frame contains information required for establishing virtual lanes on the physical link.

38. The apparatus of claim 36, further comprising means for establishing a standard Ethernet connection on the physical link when it is determined that the frame does not contain information required for establishing virtual lanes on the physical link.

39. A network device, comprising:

a plurality of ports, each port configured for communication on one of a plurality of physical links; and

a plurality of line cards, each line card configured to do the following:

logically partition traffic on a physical link into a plurality of virtual lanes;

apply a first set of rules to first traffic on a first virtual lane; and

apply a second set of rules to second traffic on a second virtual lane.

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